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THE BIOLOGY, ECONOMIC IMPORTANCE AND CONTROL OF THE PINE BARK WEEVIL, *AESIOTES NOTABILIS* PASC.

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SUMMARY.

The pine bark weevil, Aesiotes notabilis Pasc., is endemic to Australian rain forests in which its natural hosts—species of Araucaria and Agathis—are components, and is now common in extensive plantations of hoop pine, Araucaria cunninghamii. Attacks by this insect occur on plantation trees through deep bark wounds such as are inseparable from pruning operations. Larvae emerging from eggs laid on or near the branch stubs tunnel in the cambial region on the bole, invariably causing malformation and in some cases killing the trees.

Adults can live for periods of almost two years and during this time females may lay more than 700 eggs. Food, temperature and moisture markedly influence the amount and rate of oviposition. In the laboratory, eggs were laid at all temperatures within the range from 4.6 deg. C. to 32.0 deg. C., but means of more than 300 per female were laid only at temperatures from 20.0 deg. C. to 28.0 deg. C., when fresh hoop pine bark was provided as food. In the plantation, moist or wet weather always stimulated oviposition. Egg-laying was considerably reduced on a diet of hoop pine foliage, and on this food longevity was reduced above 15.0 deg. C. Without food, longevity was brief and oviposition was negligible.

Under normal conditions the incubation period varied from seven to 10 days. In relative humidities from 90 to 100 per cent. and at temperatures from 25.0 deg. C. to 27.0 deg. C. it was as short as five days, and at 10.0 deg. C. it exceeded 40 days. A moisture-saturated atmosphere is most favourable to survival of newly-hatched larvae; thus moist weather in the plantation during and following hatching of the eggs best enables the young larvae to search for and penetrate bark wounds. The maximum rate of larval development under controlled laboratory conditions occurred at approximately 25.0 deg. C., the mean total larval period for 6-instar individuals then being 54.5 days. Pupal development was most rapid in relative humidities of from 74 to 95 per cent., and the shortest period of nine days occurred at 30.0 deg. C.

Development through all the immature stages under the most favourable conditions can be completed in about 10 weeks. However, the association of laboratory data with field observations indicates that under natural conditions a generation may be completed in three months during the summer and in six to seven months over the winter period.

Natural enemies are ineffective, and insecticidal control is either impracticable or costly. Field and laboratory investigations having shown that wet weather during the warmer months is most favourable to oviposition and larval establishment and that dry, cold weather is least favourable, pruning operations are carried out during dry periods in winter, and in this way economic damage by the pine bark weevil has been eliminated.

INTRODUCTION.

The native conifer *Araucaria cunninghamii,* known locally as "hoop pine", has received a considerable amount of sylvicultural attention for reforestation in Queensland. By 1936, extensive areas of plantations had reached a stage where pruning was necessary. Though the removal of the lower green branches is sylviculturally desirable, the introduction of the practice of green pruning was followed by insect attacks sufficiently serious to threaten the welfare of established plantations and suggested that this highly desirable practice might have to be abandoned. The principal insect responsible for the attacks was *Aesiotes notabilis* Pasc. An investigation was therefore commenced, the chief purpose of which was to evolve a satisfactory means of preventing the attacks of this weevil on pruned trees. Studies were undertaken in the laboratory to define the life history and habits of the insect, and these were supplemented by field observations on habits, seasonal history, distribution, host range and environment. Special attention was directed to the effects of climatic factors on the activity and abundance of the insect, field observations in this instance being supplemented by laboratory experiments to determine the influence of temperature and humidity on development and survival. Such data might indicate whether indirect control by slight modifications in plantation management would be sufficient to obviate any need for the adoption of costly direct control measures.

REVIEW OF LITERATURE.

References to *Aesiotes notabilis* in the literature are few. Pascoe (1865), in the original description, recorded it from Queensland without mentioning a definite locality. Masters (1885-7), in his "Catalogue of Described Coleoptera of Australia", listed the insect from Pine Mountain, Queensland, and also from northern New South Wales. French (1911) recorded its presence in timber logs imported into Victoria from Queensland. Froggatt (1923) mentioned it in a discussion on a related species and later (Froggatt, 1927) recorded it from the Dorrigo district, New South Wales.

ECOLOGICAL DATA.

Host Trees and Preference.

The common name "hoop pine bark weevil" used by Froggatt for *Aesiotes notabilis* indicated that its principal host is hoop pine. Undoubtedly most of the early host records involved hoop pine, but this possibly is due to the fact that, being the most important native softwood in Australia, its extensive use made the association of the pine bark weevil with it more noticeable than with other species. In some parts of southern Queensland, where logging operations cover timber stands in which hoop vine and bunya pine, *Araucaria bidwillii,* are components, tree residues (or slash) of the latter species are just as attractive to Aesiotes adults as are those of hoop pine, and larval development proceeds in them equally well. In the rain forests of northern Queensland, exemplified by those on the Atherton Tableland, hoop pine and bunya pine are absent, and northern kauri pine, *Agathis palmerstoni,* is the dominant conifer. Aesiotes breeds freely in this species and is as abundant in these areas as in the south. The southern kauri pine, *Agathis robusta,* of which little now remains, is also attacked. In mixed plantation stands of southern kauri pine and hoop pine the insect develops in thinnings of both trees, though perhaps those of the former are less attractive to the adults. Thinnings of the variety *glauca* are as heavily infested as the type hoop pine.

A number of exotic conifer species of the genus *Pinus,* which have not been long grown in Queensland, are attractive to Aesiotes and unexpectedly the insect is capable of developing in some of them almost as well as in the native hosts. When the first thinning of a Pinus, *P. radiata,* was made in the Brisbane Valley district, Aesiotes was present although the site is located within a eucalyptus forest and is over half-a-mile from the nearest pine plantation or rain forest containing native conifers. Plantations of *P. caribaea* and *P. taeda* are established on poor, coastal hardwood forest land in the Beerwah district many miles from the nearest rain forest areas, which have mostly been cleared and utilized for grazing purposes for many years. Here again Aesiotes was active when thinning operations began; a similar occurrence was recorded in *P. taeda* plantations at Glasshouse Mountains. On the Atherton Tableland the earliest thinnings of *P. patula* and *P. montezumae* were attacked by Aesiotes, but not to the same extent as those of nearby hoop pine.

French (1911) reported *Aesiotes notabilis* from both silky oak (*Grevillea robusta*) and kauri pine logs on arrival at Melbourne from Queensland. This record of silky oak as a host has not been confirmed in Queensland and establishment of larvae in it could not be obtained experimentally (see page 36). In view of the host record of the related species *Aesiotes leucurus* Pasc. from *Callitris,* a newly pruned and thinned plantation of *C. cupressiformis* was examined; although *Aesiotes notabilis* was common in adjacent areas, it was not found in association with thinnings of this cypress, nor could larvae be established in it. The spectacular activity of large numbers of Aesiotes in hoop pine plantations when thinning operations commenced suggested the existence of natural breeding centres adjacent to the plantations, possibly in some broad-leaved species, since most naturally grown pine trees had been logged many years previously. Observations failed to reveal any such host for the insect.

A third species of *Aesiotes, A. morosus* Pasc., was described from specimens recorded on saplings of *Eucalyptus viminalis* in Victoria. If this is a correct insect-host relationship, the habits of the insect are widely different from those of the other two species, but if the presence of this insect on a eucalypt was accidental the recorded hosts of the other two species suggest that the genus is obligate to conifers.

The complete list of host trees so far recorded for *Aesiotes notabilis* is as follows:—Native Hosts:—*Araucaria cunninghamii* (hoop pine); *A. cunninghamii* var. *glauca.* (hoop pine); *A. bidwillii* (bunya pine); *Agathis palmerstoni* (northern kauri pine); and *A. robusta* (southern kauri pine). Exotic Hosts:—*Pinus radiata* (Monterey, insignis, or radiata pine); *P. caribaea* (slash pine); *P. taeda* (loblolly pine); *P. patula;* and *P. montezumae* (montezuma pine).

Distribution.

The pine bark weevil has been recorded from all rain forest areas in Queensland, from the Atherton Tableland in the north to the McPherson Range on the southern border and from Fraser Island off the coast westwards to the Bunya Mountains. Froggatt records it from the Dorrigo district in New South Wales. Its natural distribution in Australia, therefore, appears to correspond with that of rain forests in which species of either or both *Araucaria* and *Agathis* are components.

Features of the Natural Habitat.

Rain forest, also commonly called "jungle" or "scrub" in Queensland, refers to the densely canopied timber stands which reach their greatest development in coastal area with a yearly rainfall exceeding 50 inches. In such areas it is not restricted by altitude or soil type. In the high rainfall areas of coastal northern Queensland it is more or less widespread, but over most of the south-eastern part of the State, where the rainfall is less than 50 inches, it is confined to the better soil types on the highlands.

All hoop pine plantations in this State, as exemplified by those in the Mary Valley (Plate 1), are established on rain forest sites.

Change from Rain Forest to Established Plantations.

The rain forest in Queensland is a mesophytic climax containing numerous species in densely crowded stands. The transformation from this natural condition to that of established plantations is considerable and is effected as follows:—After the removal of all timber of commercial value, the remaining trees on the proposed plantation sites are completely felled during winter. At the first opportunity in the dry spring, the mass of useless timber on the ground is burnt and the young pine trees are planted immediately (Plate 2). Routine plantings of hoop pine are usually made at a spacing of eight feet between plants and nine feet between rows, which gives an average stocking of slightly more than 600 plants per acre.

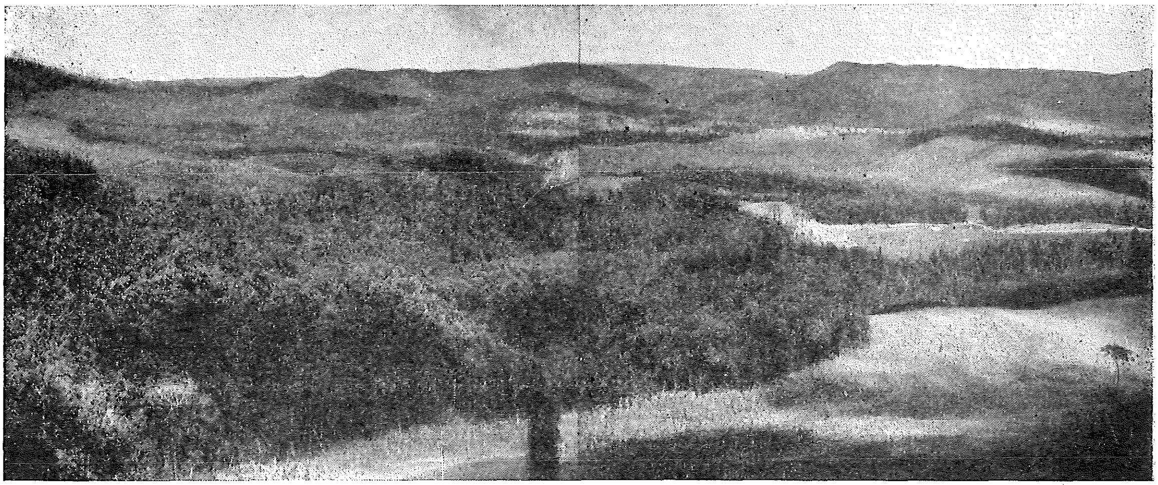


Plate 1.

Forest reserve, Mary Valley, showing topography, rain forest, and plantations in line across middle distance.

Many other plants readily appear by natural regeneration in this cleared area. They comprise a mixture of herbaceous weeds, shrubs, seedling trees and coppice. All these competitors with the young hoop pine trees are kept in check by clean chipping in the first year following planting and by grubbing thereafter until the pines are able to outgrow competing vegetation.

Alterations in the Entomological Fauna.

A complex insect population is intimately associated with the natural rain forest stand with its complexity of plants. Logging operations upset any existing balance between insects and their hosts and this has especially been the case with *Aesiotes notabilis,* for its hosts—hoop, bunya, and kauri pines—have been extensively felled in Queensland for many years and tree residues in which it breeds are abundant.

Plate 2.

Newly planted areas of hoop pine, showing complete clearing of natural forest.

Complete felling of all timber on the proposed plantation site accentuates insect development, more especially of those species associated with dead or dying trees, but this is of little consequence because within three or four months the whole area is burnt and the insect population is destroyed. The development of an insect fauna in the plantations must, therefore, result from subsequent infiltration from surrounding areas. Later, with the growth of weeds and coppice, insects of diverse habits reappear; but finally, when the pines have outgrown competitive plants, the insect fauna comprises essentially species of more or less economic importance with hoop pine as host.

Plantation Practices in Relation to Pine Bark Weevil Attacks.

Pruning.

Hoop pine plantation practice in Queensland aims at the production of a large proportion of high quality, knot-free timber. The natural progressive suppression and shedding of branches of the lower whorls on the commercial bole of hoop pine plantation trees is slow and is not commensurate with the desired minimum of core. Hence, in order that this knotty core should be restricted to a minimum, it is necessary to prune both the lower green branches as well as the dead ones from the commercial bole early in the life of the tree (Plate 3). This procedure has little effect on the vigour of the trees. Actually Paterson (1938) has shown that the cambium dies back a greater distance on dead branches than on stubs left after pruning green branches. Consequently,

Plate 3.

A pruned stand of 15-year-old hoop pine.

occlusion following "green pruning" is more rapid and causes less distortion to the grain of the subsequently formed wood than does "dead pruning". The fresh wounds, however, are attractive to insects which attack trees through injured tissues: Aesiotes belongs to this category.

Thinning.

The original stocking of pine plantations is far in excess of the number of trees required for the final crop and, therefore, thinning is carried out at intervals when root competition is expected. During the early life of the plantation, thinning follows pruning (Plates 4 and 5) in order to hasten the recovery of the selected crop trees from any temporary setback which might be caused by the pruning. The pine bark weevil attacks and breeds in these thinnings.

Description of the Extra-Cambial Tissue of a Young Hoop Pine Tree.

The bark structure of a hoop pine tree, particularly the location of resin canals, influences the intensity of Aesiotes attacks on plantation trees.

The bark of hoop pine trees exhibits a feature which is unique amongst native Queensland trees. In other species the primary phellogen, or cork cambium, ceases to function at an early age and secondary phellogen layers

Plate 4.

10-year-old hoop pine, pruned and thinned.

Plate 5.

9-year-old *Pinus taeda*, pruned and thinned.

arise in the outer cortical tissue. These are irregular in size and distribution. The bark is shed, therefore, in longitudinal strips or scales. Secondary phellogens in young hoop pine are formed in continuous circular layers, which ultimately form a true bark composed of alternating layers of cork and non-functioning phellogen. One of these phellogen layers constitutes the line of weakness during decortication and, therefore, the bark is shed in regular, circular sheets, a condition known as ''ring bark'' as contrasted with ''scale bark'' of other species.

Microscopical Structure of the Bark.

The thickness of the extra-cambial tissue of a young hoop pine tree varies along the bole, becoming thinner with height and thicker in the region of whorls than between them. In a representative bark section about 8.0 mm. in width from a seven-year-old tree the outer cork tissue is composed of about eight layers of compressed cells bounding a thin, flattened layer of old phellogen. An internal cork tissue about 10 cells in thickness and similar in appearance to the outer cork grades into rectangular cells of what appears to be a thin layer of functioning phellogen. The cortical tissue as a whole consists of about 60 layers of cells and is divided into three zones by two concentric bands of sclerenchyma. The outer zone consists of irregularly arranged, rectangular to somewhat oval cells. Between the bands of sclerenchyma the cells are irregularly arranged, but more or less rectangular in shape, while in the inner cortex they are uneven in both shape and distribution. The sclerenchymatous bands consist of several indefinite layers of stone cells. Scattered throughout the inner cortex are many resin canals with an epithelial lining, and numerous more or less isolated sclerenchymatous fibres. Endodermis and pericycle are not discernible, the demarcation between the cortex and the phloem being observable by the change in cell shape and the presence of medullary rays in the outer phloem. The phloem tissue consists of about 30 layers of cells divisible into three zones. The outer zone comprises more or less square cells somewhat irregularly arranged. Scattered throughout it are many resin canals and isolated fibres of sclerenchyma. The cells of the middle phloem zone are square in shape and fairly regularly arranged in radial rows, but smaller than those of the outer zone. Resin canals in the middle phloem are few and the walls of scattered sclerenchymatous fibres are not as dense as those in the outer phloem. The inner phloem consists of a regular series of radial rows of small, closely packed, square cells which noticeably decrease in size towards the cambium. Both resin canals and sclerenchymatous fibres are absent.

Medullary rays through the phloem are common and very narrow. Where they pass radially through the inner phloem the rays are almost straight; but, due to the presence of the comparatively large resin canals, they become bent in the middle phloem and sinuous in the outer phloem.

METEOROLOGICAL DATA.

Field Records.

Meteorological data recorded at the Forest Office at Imbil, in the Mary Valley, include screen temperature, screen humidity, precipitation, and evaporation as recorded by the Livingston evaporimeter. This station is located a little over a mile from the site where most of the field observations on the pine bark weevil were made, and although the aspects of the two sites are different the trends of the more important climatic factors recorded would be similar.

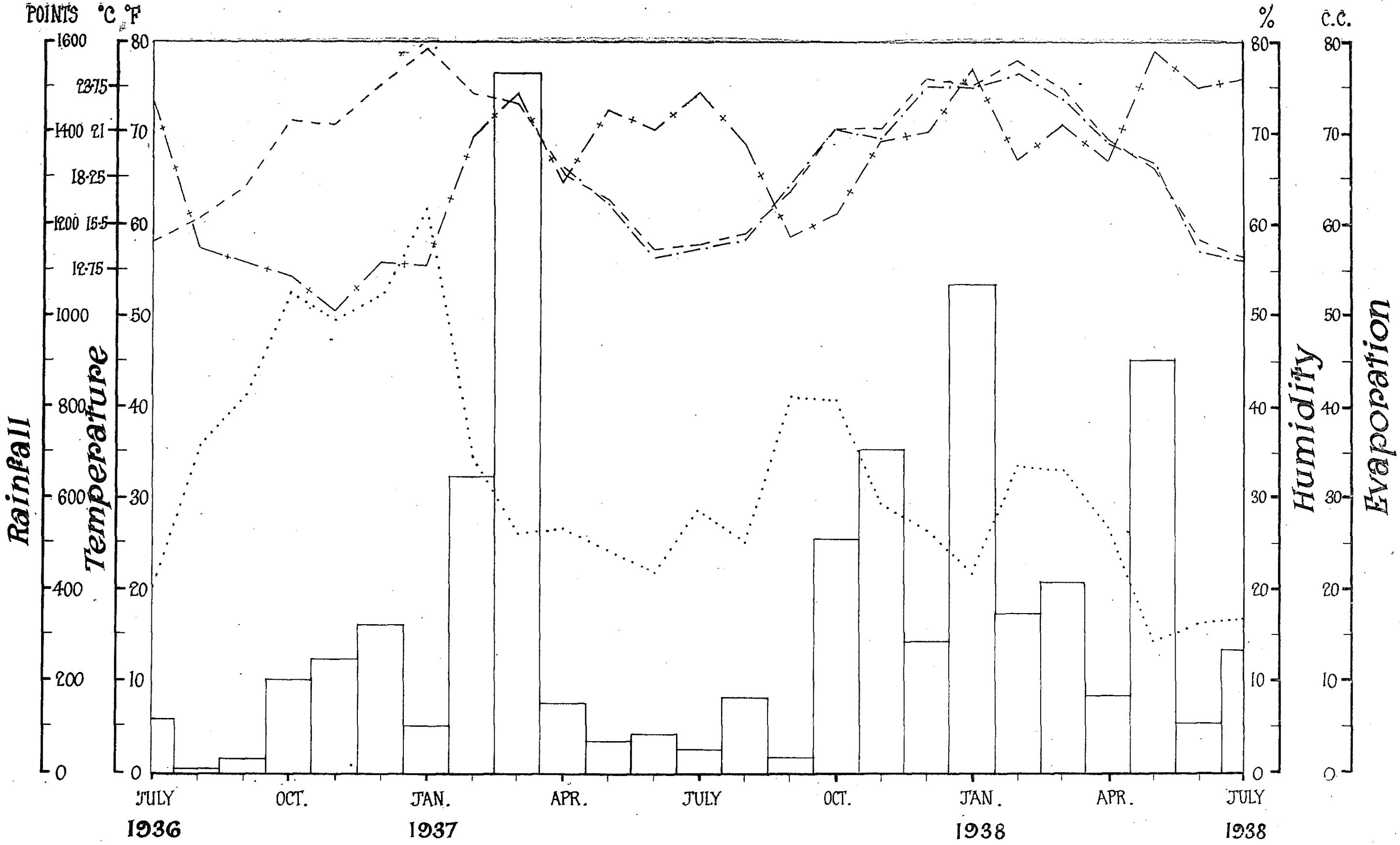


Figure 1.

Showing meteorological data from July, 1936, to July, 1938, at the Mary Valley forest station.

— — — — — — — — — Mean monthly temperature—forest station.
— . — . — . — . — Mean monthly temperature—plantation.
— + — + — + — + — Mean monthly humidity.
. . . . Mean monthly evaporation.
Histogram shows monthly rainfall.

Monthly precipitation, mean daily evaporation, mean monthly temperatures, and mean monthly relative humidities at the Forest Office for the period July, 1936, to July, 1938, are shown in Figure 1. In the first year, July, 1936, to June, 1937, 35.21 inches of rain fell. This was not very well distributed, more than 21 inches falling in the two months of February and March, 1937. The rainfall for 1937-38 was much higher—46.35 inches—and was fairly well distributed throughout the year. The peak of 11.62 inches fell in January, 1938, and there was a second peak of 9.04 inches in May, 1938.

The mean monthly temperatures show regular seasonal gradations. Commencing at 14.2 deg. C. in July, 1936, the mean rose to its peak value of 26.4 deg. C. in January, 1937; daily maxima of over 43.3 deg. C. (100 deg. F.) occurred in each of the months of December, 1936, January, 1937, and February, 1937. The lowest mean for the winter of 1937 was in June, with 14.1 deg. C., and the highest mean of the ensuing summer in February, 1938, with 25.8 deg. C. These extremes in the mean monthly temperatures for 1936-37 and 1937-38 are not widely divergent.

The mean monthly relative humidities calculated from recordings made daily at 9.0 a.m. show trends somewhat similar to precipitation, except for the winter months, when rainfalls were low and the humidities remained moderately high. The highest monthly mean over the two-year period—79.0 per cent.—was in the wet month of May, 1938, while the lowest—50.4 per cent.—was in November, 1936.

Evaporation shows inverse trends to humidity. The greatest mean monthly evaporation rate recorded over the two-year period was for the comparatively dry and hot month of January, 1937, and the lowest for the wet month of May, 1938.

During the 14 months from April, 1937, to June, 1938, complete temperature records under plantation conditions were obtained by means of a bimetallic extension-arm thermograph. The plantation canopy exercised a slight blanketing effect on temperature, the daily range being less than at the main station. The daily maxima were about 2.5 deg. C. lower, and the minima about 1.0 deg. C. higher, than the corresponding main station figures. The monthly means in the two areas can, therefore, for practical purposes be considered to be the same.

Laboratory Records.

Most of the life history studies were conducted in the laboratory at Brisbane, where room temperatures were recorded. Mean monthly temperatures were much higher than in the plantation. Commencing at the low mean of 19.4 deg. C. in July, 1936, the temperature gradually rose to a peak of 27.2 deg. C. in January, 1937. The mean for July in the succeeding winter—17.2 deg. C.—was the lowest over the two-year period while the mean of 28.1 deg. C. for February, 1938, was the greatest recorded.

An outstanding feature of these laboratory records was the very small divergence between daily maxima and minima. The greatest difference between the mean maximum and minimum temperatures for any month was 3.8 deg. C., the least 2.2 deg. C., and the mean difference 3.0 deg. C. The insects, therefore, were held under fairly even conditions of temperature, with only seasonal fluctuations.

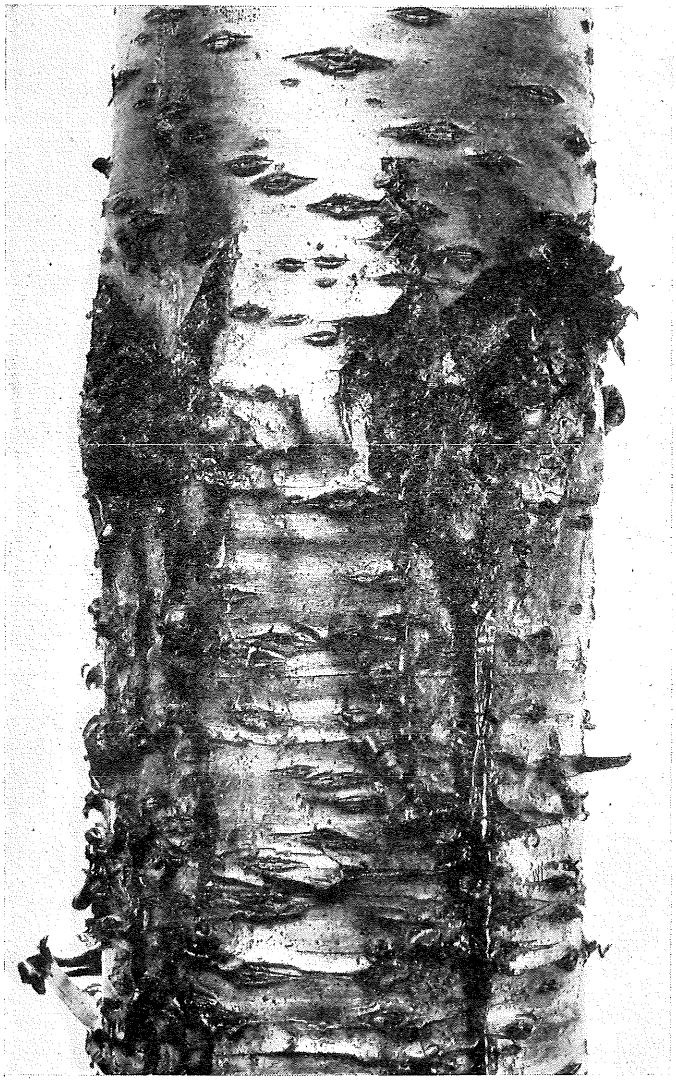


Plate 6.

External appearance of pine bark weevil attack on young hoop pine tree. Note ejected frass and discoloured seepage.

SYMPTOMS OF ATTACKS AND IMPORTANCE OF DAMAGE.

Symptoms of Attacks.

Attacks by the pine bark weevil on living trees can be initiated only in open wounds penetrating the bark to, or almost to, the sapwood. In the plantation these attacks are not noticeable until a week or more after the trees are pruned or thinned, when the larvae commence to hatch. By this time the bark on cut surfaces has lifted slightly and the young grubs penetrate into the cavities. Their location on pruned trees is indicated first by a small quantity of frass protruding from the stubs. This increases in quantity and, after mixing with the gum flow from the infested wound, seeps down the trunk (Plate 6). The normal gum flow from uninfested wounds collects in globules. At first milk-white in colour, it later changes to clear brown on oxidation and can thus be distinguished from that associated with infested stubs, where the frass gives the exudate a dirty, dark-brown colour. This discoloured seepage down the trunk is the most noticeable sign of infestation on pruned trees. Heavy attacks on thinnings are usually accompanied by large quantities of ejected material, mainly frass, at the points of larval entry on the cut surfaces.

Importance of Attacks in Natural Forests.

Wounds in the bark of living trees in the natural rain forest in Queensland are normally not common, but may occur when branches or trees collapse during strong winds. Infestations in the stubs of broken branches may in themselves be unimportant, but they assist the establishment of other, more persistent, destructive organisms. Infestations on the trunk can be more serious. On small trees the injury may extend around the bole and cause the death of the upper portion; in the case of less extensive damage, the injury itself causes a malformed and undesirable stem and, further, enables destructive pathogenic organisms to become firmly established. Owing to the thickness and toughness of the bark, wounds on the boles of large trees are rare and infestation on these is not common.

Nature and Importance of Damage to Plantation Trees.

Attacks on plantation hoop pine trees by the pine bark weevil are mainly associated with injuries received during pruning. Damage is caused by the larvae which, after emergence from the eggs, enter the cambial region of the stubs and follow it to the bole. Feeding takes place largely on the inner bark tissue, but may include the thin cambium and the newly-formed tissue on the surface of the wood. Tunnelling gradually encircles the stub, the larvae being accommodated in the depression surrounding its base (Plate 7). Should the available food in this position become exhausted before larval development is complete, tunnelling may extend to an adjacent stub or, more commonly, follow the longitudinal direction of the basal depression and extend along the bole. Such an extension of damage soon occurs when more than one grub infests a single stub (Plates 6 and 9). The thickness of the bark at a whorl, where the

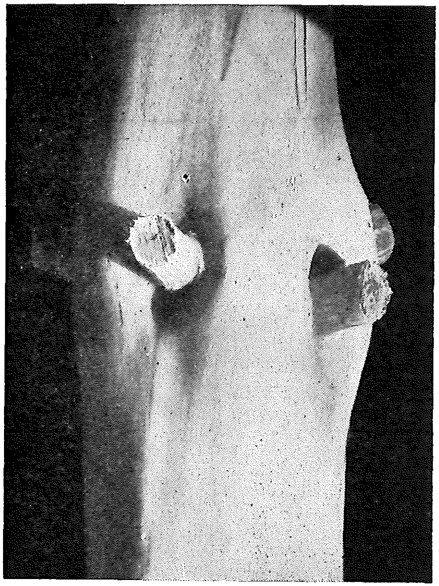


Plate 7.

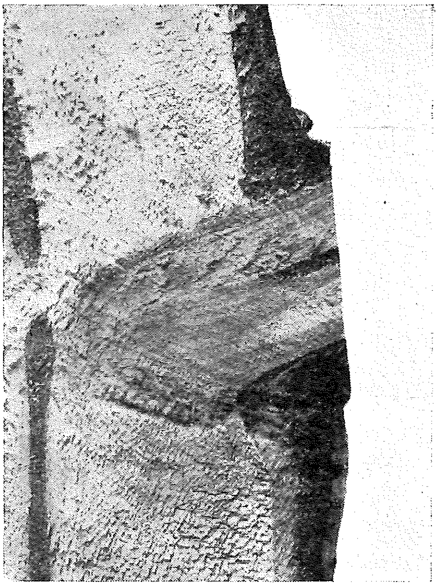


Plate 8.

Structure of Whorl and Stub in Hoop Pine.

Plate 7.—Stem of a hoop pine tree in the region of a whorl of pruned branches, with bark removed, showing the magnitude of the basal depression.

Plate 8.—Section of a hoop pine stem, showing thickness of bark and basal depression.

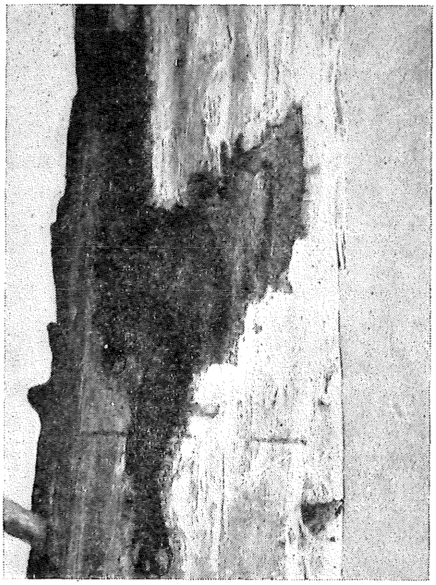


Plate 9.

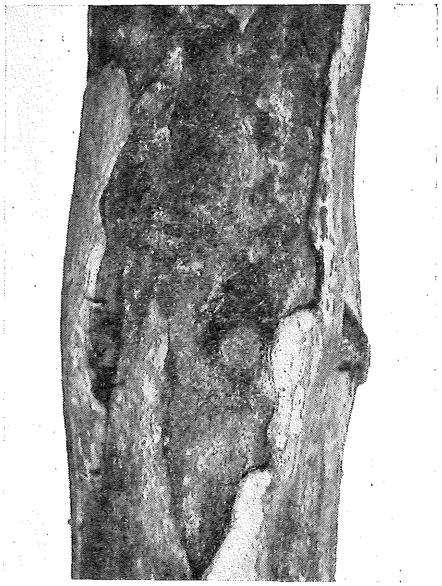


Plate 10.

Aesiotes Injury to Hoop Pine.

Plate 9.—Stem of a hoop pine tree, with bark removed, showing damage caused by three pine bark weevil larvae which entered the same stub.

Plate 10.—Stem of a pruned hoop pine tree killed by pine bark weevil larvae, with bark removed, showing extent of damage and incomplete occlusion.

larvae normally enter (Plate 8), is much greater than that between whorls. The food available about a stub may thus be sufficient for a single grub and the damage is then localized. Such mild attacks are rare and it is more usual to find several larvae associated with each infested stub, with the resultant outward extension of the damage. Following cessation of larval activity in such a case the wound commences to heal from the edges, but there is a comparatively large surface to be occluded. In the meantime, girth increment is uneven and the defect may persist. In addition, secondary borers and fungous rots may enter and cause further serious damage.

When two or more stubs in the same whorl are each attacked by a single grub, subsequent growth produces a very irregular cross section in the stem. The most serious injury follows the entry of several grubs into each or most of the stubs of the same whorl (Plate 10). Tunnelling rapidly extends outwards and may result in the destruction of the phloem in a complete band round the girth; the effect on the tree is then similar to that of ringbarking or girdling. In such cases the crown may live for a time, with occlusive tissue forming on the upper side of the injury, but the tree ultimately dies. Even if the bark is not completely severed, secondary organisms may invade the tree either at or above the injury and produce the same result.

Larvae of the pine bark weevil also produce timber defects on pruned trees in another way. It is not unusual for some larvae to enter the comparatively large pith of the green stubs. Although the pith is an unsuitable food, larvae can live in this position for several weeks, producing upwardly pointing cavities in which water collects and sponsors the onset of rots in the adjacent wood.

When first begun, green pruning was followed by serious pine bark weevil attacks. The work was carried out in the Mary Valley, but because of the general distribution of the insect similar attacks in other hoop pine reforestation areas could be expected. Thus it appeared that, in the sylvicultural programme, the practice of green pruning hoop pine might have to be abandoned and that the objective of keeping the knotty core of the trees to a desirable minimum could not be achieved.

Pine bark weevil attacks of a very different kind have occurred on tubed kauri pine and hoop pine plants in the Gadgarra nursery on the Atherton Tableland. The damage was caused by larvae tunnelling in the main roots, of necessity chewing away woody tissue as well as bark, finally forming cocoons for pupation at or near ground level (Plate 11). Moist weather conditions, favourable to pine bark weevil activity, prevailed during tubing operations and the tubed stock was not returned to the nursery beds for a few weeks. It appears that the cut ends of the roots of these large plants protruded slightly below the soil in the tubes. Adults attracted to them must have laid eggs on the injured roots and young larvae penetrated the tissues before the plants were returned to the nursery beds. Having established themselves, the larvae tunnelled upwards through the roots until development was complete, one

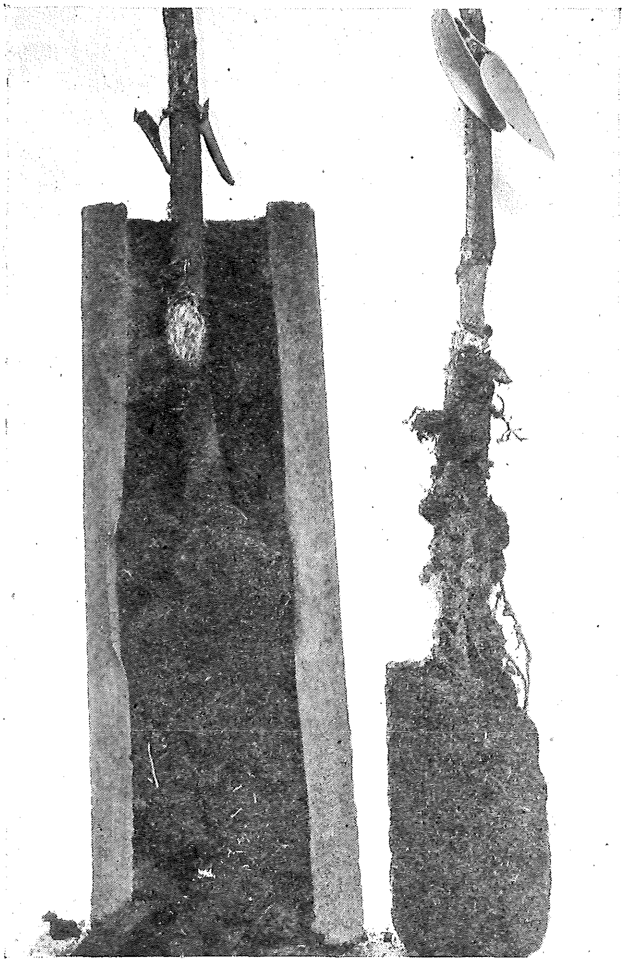


Plate 11.

Nursery kauri pine seedlings killed by pine bark weevil larvae tunnelling in the roots.

grub reaching maturity in each root. In this way a loss of 15 per cent. of plants 12 or more inches in height was occasioned; smaller tubed plants and undug plants were not attacked.

SYSTEMATICS AND DESCRIPTIONS OF STAGES.

Systematic Position.

The genus *Aesiotes* belongs to the subfamily Aterpinae of the family Curculionidae and was erected by Pascoe (1865) to accommodate *A. notabilis,* the species now under discussion. Since that time, only two species have been added to the genus, both by Pascoe in 1873. *Aesiotes morosus* was described from specimens recorded on saplings of *Eucalyptus viminalis* in Victoria. The third species, *Aesiotes leucurus,* was described from New South Wales, where it was classed as a destructive pest of introduced conifers. It also occurs in Queensland, the recorded hosts being native species of *Callitris*. The genus *Aesiotes* thus appears to be indigenous to eastern Australia.

Vernacular Name.

Froggatt (1927) designated *Aesiotes notabilis* "the hoop pine bark weevil"; but, since the insect is partial to species of conifers other than hoop pine, the common name "pine bark weevil" seems preferable. Several other weevils tunnel into the bark or between the bark and sapwood of conifers in Queensland. Few of them are associated with living trees, however, and as *Aesiotes notabilis* so far is the main species of economic importance, the name "pine bark weevil" is preferable for this insect.

Description of Stages.

Description of the Egg.

The egg (Plate 12, fig. 1) is smooth and ellipsoidal in shape, approximately 1·4 mm. in length and 0·8 mm. in width. The colour is at first uniformly milky-white, but as incubation progresses it gradually darkens to a creamy-white, with brown tinges marking the mandibles of the embryo. Apart from normal variations in egg size, there is a noticeable difference in passing from one season to another. Winter eggs, with an average length of 1·60 mm. and a width of 0·86 mm. are consistently larger than those laid in summer, when the average length is 1·21 mm. and the width 0·76 mm.; greater variation is shown in the length (Table 1).

Table 1.

Dimensions of the Egg (in mm.).

Month.	Minimum.		Maximum.		Mean.	
	Length.	Width.	Length.	Width.	Length.	Width.
July	1·50	0·81	1·68	0·89	1·60	0·86
August	1·44	0·80	1·58	0·89	1·48	0·83
September	1·28	0·80	1·54	0·88	1·43	0·85
October	1·27	0·78	1·44	0·85	1·33	0·82
November	1·04	0·70	1·39	0·83	1·21	0·76

Description of the Newly Emerged Larva.

The young larva (Plate 12, fig. 2) on emerging from the egg has a slender, slightly flattened body narrowing posteriorly. It varies from 2·5 mm. to 3·0 mm. in length and averages 0·43 mm. in width. The widest part of the larva is the head capsule, which averages 0·48 mm. Numerous comparatively long hairs cover the body and these are shortest on the ventral surface. At first the body is pale-yellow in colour, but becomes creamy-white after feeding. The head capsule is a pale yellowish-brown, while the sharp, bifid mandibles are dark-brown in colour.

Description of the Mature Larva.

Body.

The full-grown larva (Plate 12, fig. 3) ranges in length from 22·0 mm. to 27·0 mm. and averages 6·0 mm. in width. It is stout, fleshy, and wrinkled, and is white in colour until just before pupation, when it becomes pale-yellow. It is subcylindrical, with the ventral side slightly flattened, tapers gradually towards the posterior end, and is not ventrally curved during active life.

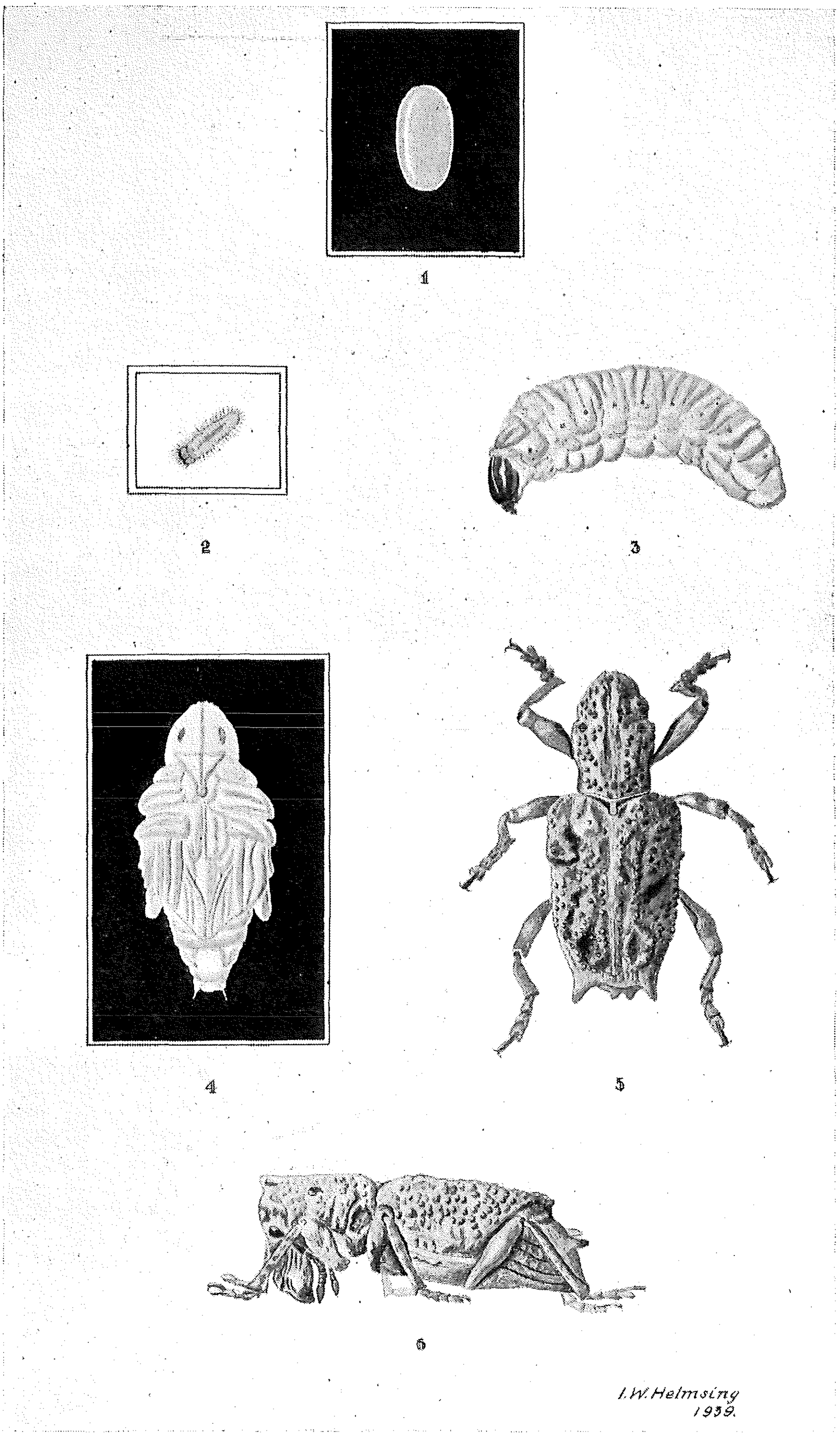
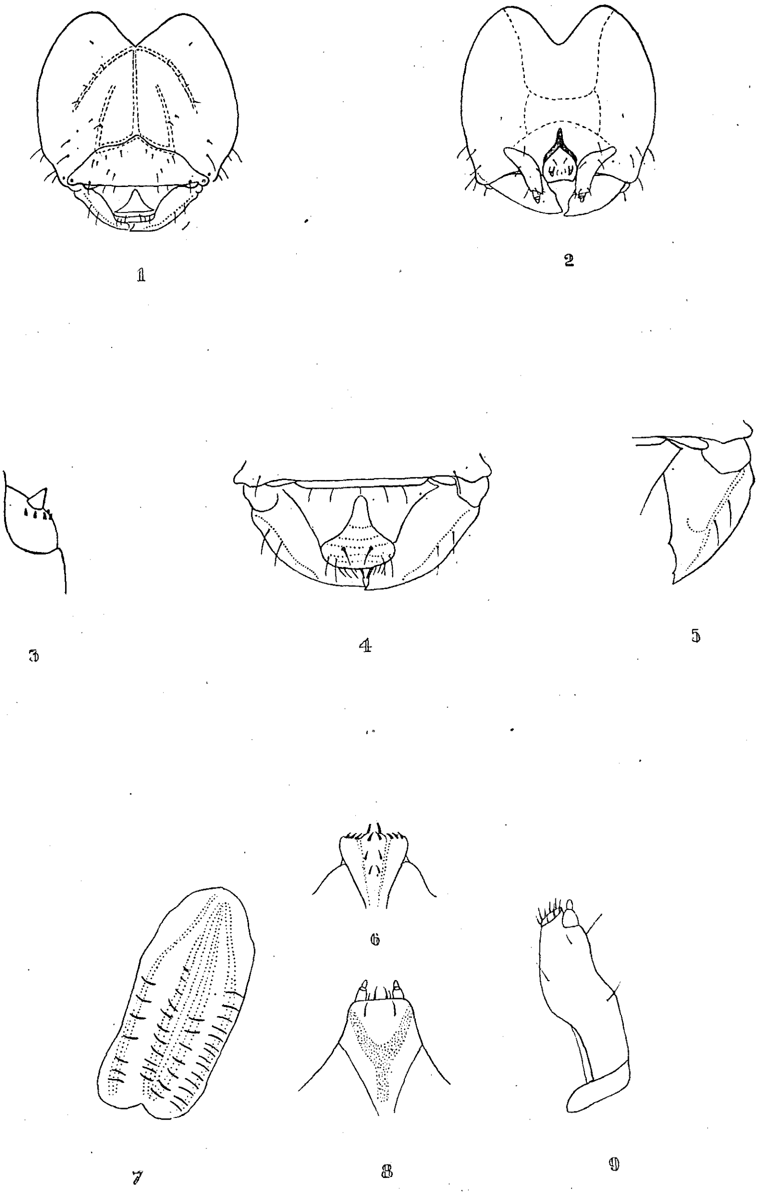


Plate 12.

Pine bark weevil. Fig. 1, egg x 10; fig. 2, larva—first stage x 3; fig. 3, larva—full-grown x 2; fig. 4, pupa—ventral view x 3; fig. 5, adult—dorsal view x 3; fig. 6, adult—lateral view x 3.

Head Capsule. (Plate 13, figs. 1 and 2.)

Chitinized, dark yellowish-brown, the entire mouth frame and mandibles much darker. Sub-circular, the width slightly exceeding the length from the anterior margin of the closed mandibles to the occipital foramen. Cheeks broadly rounded. Angle of occipital foramen slightly exceeding 90 degrees. *Epicranial suture* distinct; slightly exceeding half the cranial



Helmsing et Brimblecombe.

Plate 13.

Larval characters of the pine bark weevil. Figs. 1 and 2, head capsule; fig. 3, antenna; fig. 4, mouth parts; fig. 5, mandible; fig. 6, labrum; fig. 7, spiracle; fig. 8, labium; fig. 9, maxilla; (Figs. 1, 3, 4 and 5 dorsal view; figs. 2, 6, 8 and 9 ventral view).

length; basal two-thirds bordered by dark-brown; distal one-third bordered by yellow, basal one-third apparently not fused. *Frontal suture* distinct; each arm about equal to epicranial suture in length, sinuate; basal two-thirds bordered by yellow, then appearing as a narrow, pale line. *Adfrontal suture* distinct and large; slightly more than two-thirds length of epicranial suture and reaching from the arm angle of the frontal suture towards the occipital foramen and bordered by yellow. Arising at the occipital foramen and extending forward in a curve, outside the adfrontal suture and towards the antennae, is a cranial suture noticeable by its border of dark-brown; the groove and the colour gradually diminish and become indiscernible half-way along the epicranium. On the cheek is a short, longitudinal suture bordered by yellow. *Ocelli* distinct as pale spots just behind the antennae. *Setae,* 13 on each epicranium, five major, three medium and five minor. *Frons* subtriangular, twice as wide as long, length three-quarters of epicranial suture; median frontal carina well defined, extending forward about half the length of frons; three pairs of major setae, four pairs of minor. *Antennae* (Plate 13, fig. 3) small; in lateral angle of frons; basal segment dome-shaped; apical joint conical, carrying five small, tactile papillae. *Clypeus* broadly transverse; length about three times the width; provided with two pairs of setae on the posterior margin. *Labrum* (Plate 13, figs. 4 and 6) transverse, length about half of width and half length of clypeus; upper surface carrying four pairs of setae, the median pair longest, directed outwards and located on slightly raised areas, the posterior margin prolonged triangularly; anterior margin truncate, but three-lobed, the outer pair of lobes in the epipharyngial region carrying three dagger-like setae directed inwards, the median lobe with two similar but larger setae; ventrally provided with three pairs of short setae spaced between the epipharyngial rods, anterior pair shortest and closest, median pair longest and spaced widest. *Mandibles* (Plate 13, fig. 5) strong, subtriangular with broad base, distally provided with an apical and a subapical tooth, with a large blunt and a small pointed denticle one-third the distance back along the slightly curved inner margin; two setae in a suture on the external face. *Maxillae* (Plate 13, fig. 9) cardo smooth, setae absent; stipe with a basal latero-ventral seta, two setae in palpiferous region, one lateral and one ventral; palpus two-jointed; basal joint slightly more than twice as wide and twice as long as the apical joint, which is longer than wide, finger-like and surmounted by papillae; mola single, tip obtuse and rounded, reaching to base of apical joint of maxillary palp; buccal face with 10 stout, dagger-like setae, seven dorsal, three ventral; sub-facial region undivided, formed by the fusion of the articulating areas of the mentum, submentum and maxillae and with two pairs of major and one pair of minor setae. *Labium* (Plate 13, fig. 8) stipes fused medianly; posteriorly limited by a Y-shaped, chitinized band; one major setae on each labial stipe; palps two-jointed, similar to maxillary palps, but smaller in size; ligula with two pairs of setae anteriorly.

Thorax.

Terga of prothorax simple, with 10 pairs of balanced setae. Meso- and meta-thorax divisible into prescutum, scuto-scutellum and alar area. Prescutum with one pair of spines; scuto-scutellum with four setae in a straight line, largest outermost; alar area with two pairs, a major and a minor. Epipleurum of prothorax triangular, with three major and one minor setae. Postepipleurum very small. Hypopleural and sternal areas of all thoracic segments similar in position and shape. Hypopleurum triangular, with two setae on the prothoracic lobe and one on each of meso- and meta-thoracic lobes. Presternum absent in each segment. Eusternum large, with a pair of setae. Parasternum triangular, with six setae.

Abdomen.

Abdomen of nine segments, the first six similar in shape and size though diminishing slightly in width posteriorly, the last three reduced and modified in size. Tergum divided into prescutum, scutum, scutellum and alar area. Prescutum with one pair of setae, scutum without setae, and scutellum with five on each side; alar area with a major and a minor seta. Epipleurum and hypopleurum lobular, each with two setae. Eusternum larger than thoracic eusterna, with two pairs of setae. Parasternum lobular, angular, with one seta. Seventh segment smaller, alar area prominent and somewhat dorsally situated, similar in form to segments 1-6. In eighth segment, prescutum and scutum are fused, two setae again present; scutellum with three pairs, alar area with one, the major seta absent; epipleurum, hypopleurum and eusternum as in segments 1-6; alar area more prominent. Ninth segment of four lobes; inner pair constitute the tergum and represent the posterior end of the body; each inner lobe bears three setae, two major terminal and one minor; epipleurum with major and minor setae; sternum with two pairs of setae. *Spiracles* (Plate 13, fig. 7) biforus, almost perpendicular to length of body, the opening longitudinal, present on prothorax and abdominal segments 1-8. Prothoracic spiracle placed posteriorly in alar region, abdominal spiracles almost medianly placed. Passing back from the sixth abdominal segment the spiracles become slightly more dorsal until on the eighth segment they are almost dorsal.

Description of the Pupa.

The mean length of the pupa (Plate 12, fig. 4) for both sexes is 13·4 mm. and the mean width 6·7 mm. The colour is at first uniformly white, but later becomes pale-brown.

Rostrum larger than rest of head, bearing a number of paired spines, which are stoutest on the more prominent positions. Antennae stout, lying laterally along the prothorax and resting on the femora of the forelegs. Eyes in the depression between the rostrum and forehead, which is rounded with two prominent anterior and two stout lateral spines, all borne on raised bases.

Prothorax rounded, smooth except for the raised bases of the prominent spines, which consist of an anterior pair, three median pairs and four posterior pairs. Meso- and metathorax dorsally have three pairs of spines. Each abdominal segment from 1-7 bears four pairs of spines spaced across the segment. These become stouter and their bases larger until on the seventh segment they appear as large hooks. Segment 8, dorsally with a pair of inwardly pointing spines. Segment 9 with two large postero-lateral, straight spines. Ventral surface without spines. Fore- and mid-legs folded over, and hind legs under, the elytra. Femora distally with two stout spines. Elytra curved ventrally, protuberances prominent. Spiracles present on abdominal segments 1-5.

The pupae of males are slightly smaller than those of females (Table 2).

Table 2.

DIMENSIONS OF THE PUPA (in mm.).

——	Female.		Male.	
	Length.	Width.	Length.	Width.
Minimum	12·0	6·0	10·0	5·5
Maximum	16·0	8·0	15·0	7·5
Mean	13·7	6·7	13·1	6·7

Description of the Adult.

(Plate 12, figs. 5 and 6.)

As the genus *Aesiotes* was erected by Pascoe (1865) to accommodate *A. notabilis*, the original generic description given below refers especially to this species.

"**Aesiotes.**

Rostrum crassum, difforme, medio haud sulcatum, *Scrobe* obliqua, profunda, submargine oculi, tingente, *Oculi* subprominuli, infra angustati, acuminati, *Antennae* subapicales; *scapo* brevi, oculum attingente; *funiculo* 8-articulate, duobus basalibus, longiusculis; *clava* ovata, *Prothorax* angustus, oblongus; lateribus irregularis, basi basinuatus, apice supra productus, infra late emarginatus, lobus ocularis valde determinatus et ciliatus, *Scutellum* oblongus, *Elytra* prothorace basimulto latiora, inaequalia, postice declivia, *Pedes* subteretes, *femoribus* subclavatus muticis; *tibiis* rectis. inermibus, corbulis posticia apertis; *tarsis* articulus, tribus basalibus latitudine fere aequalibus, art. ultimo elongata; *unguibis* libertis, *Metasternum*. elongatum; *Abdomen* segmentis duobus basalibus majoribus. *Processus* interfemoralis anguste subrotundates.''

''A remarkable genus allied to *Leptops**, but radically distinct in its open posterior corbels, differently formed rostrum and elongate metasternum.''

''*Aesiotes notabilis*, oblongus, niger, squamis griseometallicis ornatus; capite, fronte et supra oculos depresso; rostro squamoso, basi linea arcuata impressa, dein gibboso, lateribus sulcatis, apice triangulariter impresso; antennis scapo squamoso, funiculo parce setoso; prothorace fere duplo longiore quam latiore, quadri subseriatim longitudinaliter tuberculato, apice tuberculus duobus elevatis instructo lateribus fusco nebulosis; acutello basi constricto, elytris subovatis, dorse depresso, tuberculato, fuscescente, lateribus seriatim curvatosculatis, sulcis subfoveatis, interstitiis, tuberculatis, postice, exeuntibus, declivitate tuberculo elongato instructa, apice dehiscentia, obtuse mucronata corpore infra pedibusque dense griseo-squamosis, Long. 7 lin. Hab. Queensland.''

The various mean body measurements of the adults are shown in Table 3.

Table 3.

DIMENSIONS OF THE ADULT (in mm.).

——	Female.			Male.		
	Minimum.	Maximum.	Mean.	Minimum.	Maximum.	Mean.
Prothorax, length ..	3·5	5·5	4·8	3·0	5·5	4·6
Prothorax, width ..	2·5	5·0	3·4	2·2	4·0	3·3
Elytra, length	8·0	11·2	10·0	7·0	10·5	8·8
Body width	4·5	6·5	5·9	3·5	6·5	5·4
Total body length ..	11·5	16·7	14·7	9·0	16·0	13·7

The length of prothorax, width of prothorax, length of elytra, body width and total body length of the males are all smaller than in the females. No other external differences are discernible.

DEVELOPMENT AND HABITS.

Observations under natural conditions in the plantation on an internally feeding insect, such as the pine bark weevil, do not give precise information on the life history, and a breeding technique was, therefore, devised in the laboratory. Eggs laid by weevils collected in the field were used as a starting point in work which subsequently gave a complete picture of the immature stages.

The Egg.

Place of Oviposition.

As is the case with most other phytophagous insects, the pine-bark weevil places its eggs on or near the plant tissues which constitute the larval food. Small, brown spots on freshly-cut surfaces were first recognized as eggs

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* *Leptops* is now regarded as a synonym of *Baryopadus* Pasc.

when egg-laying was induced in the laboratory. They were then found without any difficulty on the stumps and butts of thinnings in the plantation and also on the stubs of pruned trees. Eggs laid in the plantation are almost invariably placed on rough surfaces and more especially in depressions such as the rough grooves of axe cuts and splintered surfaces (Plates 14 and 15). Following pruning operations, eggs are laid most freely on the stubs with a jagged surface.

Plate 14.

Pine bark weevil eggs laid on rough injured bark. close to the stub of a pruned tree.

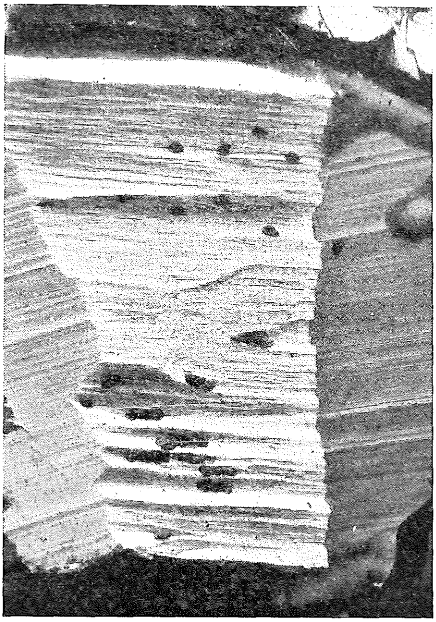

Plate 15.

Pine bark weevil eggs laid on the rough surface on the butt of a hoop pine thinning.

Egg counts in the plantation showed that more than twice as many eggs were laid on the wood as on the bark where the larvae enter. A large series of paired weevils was kept under observation in the laboratory and counts were made of the number of eggs placed in each of the several sites available for oviposition. The insects were held in glass tubes plugged with cotton wool, provided with a rough piece of wood, and regularly supplied with fresh hoop pine bark as food. The distribution of eggs was as follows:—On wood, 21 per cent.; on bark, 48 per cent.; on wool plug, 28 per cent.; and on glass, 3 per cent. A decided preference was shown for depressions on the rough edges of pieces of bark, and the next most favoured site was the cotton wool plug, which also presented an uneven surface. Wood, therefore, was not used in subsequent breeding work; the preference for wood in the plantation is probably due to the surface being rougher than that of the bark.

Oviposition.

Oviposition is essentially a nocturnal operation, though it may occur on very overcast days or in suitably dark situations. The gravid female wanders about in search of a suitable site. Having chosen one, it extends the ovipositor into the depression and places the egg in it. When the egg is laid, the ovipositor is retracted, but the tip of the abdomen remains extended and emits a fluid-like material which spreads over and about the egg, completely enclosing it. Only a few minutes may elapse between the laying of consecutive eggs. In the plantation more than 12 eggs may be found together, but they are probably not laid by a single female at the one time, because records show that this number is far above the normal daily oviposition rate for the species.

The egg cover at first appears to be semi-liquid, but it contains undigested sclerenchymatous fibres from the alimentary tract. Eggs laid by adults fed on bark have a cover which is at first greyish in appearance; but in the plantation, where foliage may be included in the food, the cover is at first greenish-grey. In both cases, the colour finally changes to dark-brown. Twelve hours after oviposition the cover is still soft, but later it becomes hard and cannot be dissected away without breaking the egg. This cover probably serves as a protection against natural enemies and desiccation. Eggs laid by females which have been deprived of food for some time are not covered.

Oviposition Records.

The adult life and the period of oviposition are very lengthy. Some field-collected females outlived the period of approximately five months during which they were under observation. The oviposition records of paired insects (Table 4) are, therefore, the actual figures obtained and do not necessarily express the total oviposition capacity of each female, which would, of course, include eggs laid before capture and any which might have been laid after recording was terminated. Egg-laying by laboratory-bred adults was lower than that by field-collected specimens. The greatest number of eggs recorded for a single female was 749; this individual was collected in the field and was still alive when observations ended. In one period of 17 days it maintained a daily mean of 7·5 eggs, but for the whole observation period of 206 days the mean was only 3·6 eggs per day. The greatest rate of egg-laying achieved by any female for a short period was 59 eggs in three days. Means of about 10 eggs per day were not uncommon for short periods though as the insects aged the rate declined. As the adult may live for 18 months or more and egg-laying extends over most of this period, it may be assumed that the potential reproductive capacity of the female exceeds 500 eggs, which appears to be high for a Curculionid when compared with available oviposition records of weevils elsewhere.

Incubation Period.

Preliminary observations in the laboratory showed the average incubation period to be eight days. Variations from seven to 10 days occurred, however, amongst eggs laid on the same day. In August, 1936, for which month the mean

Table 4.

OVIPOSITION RECORDS OF FIELD-COLLECTED FEMALES.

Lab. No. of Mated Pair.	Date Collected.	Date of Last Recorded Egg.	Total Eggs Laid.	Date of Death of Female.	Period of Observed Oviposition (Days).	Mean No. of Eggs per Day.
4	15–4–37	7–8–37	174	*	114	1·5
15	16–4–37	27–9–37	456	*	164	2·8
46	17–4–37	10–7–37	307	30–7–37	84	3·8
47	17–4–37	2–10–37	299	23–11–37	168	1·8
48	17–4–37	27–9–37	259	*	163	1·6
51	17–4–37	10–8–37	482	9–9–37	115	4·2
54	17–4–37	7–10–37	418	8–11–37	173	2·4
60	18–4–37	7–10–37	505	*	172	2·9
64	18–4–37	7–10–37	510	*	172	3·0
112	20–4–37	10–7–37	173	*	173	1·0
162	17–5–37	2–10–37	279	*	138	2·0
178	17–5–37	2–10–37	168	*	138	1·2
189	17–5–37	7–10–37	401	*	143	2·8
233	18–5–37	17–6–37	179	12–7–37	30	6·0
297	19–5–37	12–12–37	749	*	206	3·6
299	19–5–37	4–10–37	337	*	138	2·4
309	19–5–37	24–9–37	323	22–10–37	127	2·5
312	19–5–37	5–10–37	470	8–11–37	139	3·4

* Female still alive when observations ceased.

temperature was 20·1 deg. C., the mean incubation period was 8·4 days, while in September, with a corresponding temperature of 22·5 deg. C., it was reduced to 7·6 days. Such a difference is sufficient to indicate that under plantation conditions the development rate would vary appreciably throughout the year.

Development of the Egg and Hatching.

Changes during incubation were observed on eggs from which the protective cover had been removed immediately following oviposition. Within a few days the milky-white colour changes to creamy-white, soon to be followed by a faint but noticeable darkening towards one end, marking the position of the developing mandibles. Prior to hatching, the outline of the pale-brown head capsule can be seen. The shape of the egg becomes slightly altered, but such an alteration would not normally be possible in naturally placed eggs with the rigid protective cover.

Late in the incubation period the larval body is flexed ventrally, and alterations in the position of the grub in the egg can be effected by a backward movement. This sometimes is necessary in order to attain the correct orientation for emergence. The small, round, emergence hole made by the sharp, bifid, pincer-like mandibles corresponds in size with the head capsule and is always located on the outermost surface towards one end of the egg. Once the head capsule—the widest part of the young grub's body—is free the remainder of the body is slowly withdrawn from the egg.

The Larva.

Laboratory Breeding Technique.

Detailed life history studies on plantation trees were quite impracticable and therefore a method for the laboratory breeding of the internally feeding larvae of the pine bark weevil had to be devised. In anticipation of a long life cycle, food difficulties had to be overcome before normal development of the immature stages could be expected. Tree trunk sections up to eight inches in diameter and three to four feet in length can be held in a comparatively fresh state for more than a month if the ends and stubs are coated with crude lanoline. Under these conditions the practically impervious, parchment-like outer bark prevents desiccation, and breakdown of the soft inner bark is negligible. Newly-emerged larvae were established in these tree trunk sections by placing them in lateral cuts penetrating to the cambium. The grubs immediately entered the fresh inner bark. Though some re-emerged and were lost, and others became entangled in the gum exudate, many completed their development.

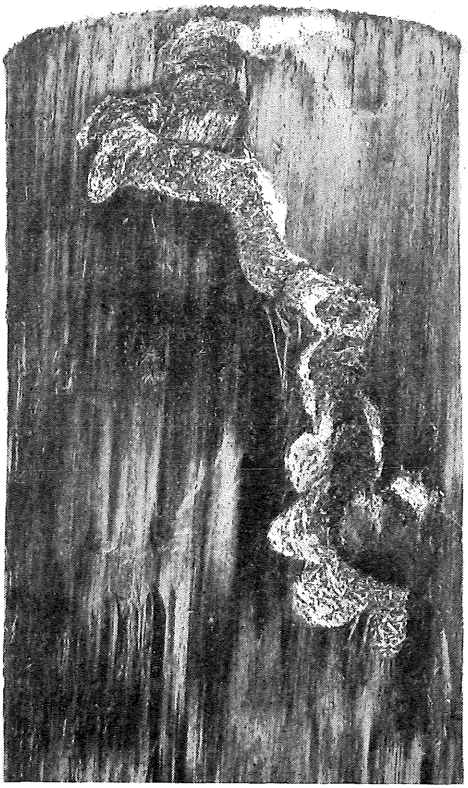

Plate 16.

Tunnelling of a pine bark weevil larva, exposed by removing the bark from a hoop pine breeding block.

Improvements in technique were later effected by cutting the portions of tree trunks into blocks six inches in length and sealing the cuts as previously. Blocks of this type (Plate 16) remained fresh and provided sufficient food for several larvae for four weeks. The harmful effect of the exudate was almost completely overcome by placing the larvae in crevices made by raising the phloem slightly from the sapwood on the transverse ends, damage to the grubs and re-emergence in this case being prevented by closing the crevice with a piece of cotton wool. A further application of lanoline resealed the cut end. In this way six larvae were inserted at even distances around the cambium on one end of each block. In anticipation of a lengthy larval life, monthly examinations were planned with the object of securing some definite data on the number of larval stages and the duration of each; however, development was so rapid that many of the grubs had become almost full-grown within four weeks. Immediate examination of all blocks showed that even after the elapse of two weeks some grubs had advanced to the third stage. All grubs were transferred to new blocks; even large grubs could be successfully handled in this way. It was realized, however, that, because of the frequent examinations necessary in a detailed study of each larval stage, the blocks were unsuitable, though they provided information on the total larval period.

The experience gained in handling the larvae suggested a further modification in the breeding technique, whereby pieces of bark two inches long and one inch wide were cut longitudinally from the tree sections and bound in pairs with the phloem areas contiguous. Individual larvae were placed between the pieces of bark and the whole immediately transferred to small, screw-capped, glass jars to prevent excessive drying. The crevices between the pieces of bark normally gave each young grub a suitable position at which to commence feeding. This technique satisfactorily permitted daily examinations and frequent renewals of food.

Habits of the Young Larva.

In the plantation the eggs of the pine bark weevil are laid mainly in positions from which the newly hatched larvae must seek their own feeding site. They may thus be temporarily exposed to many hazards. These larvae, though legless, can crawl with ease on a moist surface but move with difficulty on a dry surface. They wander in any direction and seem to arrive at suitable tunnelling sites by chance; however, they always crawl beneath bark projections or into crevices and some eventually find the cambium on the cut surface near which the eggs were laid. By the time the eggs have hatched, the cut surfaces of pruned stubs have been exposed for some days and drying causes the phloem to lift slightly from the sapwood. It is into these crevices that the grubs normally enter and they are soon protected by fibres torn away from the phloem and packed behind them, apparently before commencing to feed.

Larval Food and Habits.

Normally, the young larvae feed on the inner surface of the phloem but may include the adjacent cambium and newly formed xylem. The phloem alone, however, constitutes a satisfactory diet. Young grubs established in experimental blocks usually turn away from the line of entrance and tunnel for some distance across the grain, within green tissue, but just beyond the margin of drying tissue. Later the tunnelling reverts to the direction of the grain and continues more or less in this direction in green tissue for the remainder of larval life. By the time it veers in the direction of the grain, the tunnel has become a quarter-of-an-inch in width, having been made by a grub then in the third stage. The manner of tunnelling differs from that of most tree-boring insects in that the larva advances through the phloem on a comparatively broad face and occupies a rather large cavity. The size of the cavity facilitates the transference of waste and non-ingested material to the rear. This is effected partly by sweeping head motions. Periodically the larva reverses its position and, using its head, compresses the debris into the older part of the tunnel, giving it a characteristic backwardly-curved appearance. With increase in larval growth, the tunnel includes a greater proportion of phloem; consequently tissue destruction by the more mature larvae is comparatively rapid. Most larvae in breeding blocks with a phloem thickness of one-sixth of an inch or more completed development by feeding in this tissue alone. In blocks with a thinner phloem, the tunnel encroached on the sclerenchymatous layer, though this does not provide food. In very thin bark, the tunnel penetrated through the stone layer and the cortex to the phellogen, leaving only a thin strip of cork as an exterior protection. The distance tunnelled by larvae in experimental blocks varied to some extent, depending on the thickness of the phloem tissue available as food. In blocks with a thick phloem the tunnel length rarely exceeded six inches, but it extended to eight inches in blocks with thin phloem. In blocks of *Pinus* spp.—especially *P. radiata*—with a thinner bark than hoop pine, the tunnel often reached a length of eight inches by the end of the third instar and a total length of 12 inches.

In the later laboratory work, young larvae placed between pieces of fresh bark first tunnelled in the crevice between them but soon penetrated into the phloem of one or other of the pieces. Tunnelling continued in this tissue, gradually increasing in depth to the sclerenchymatous layer. Older larvae broke through the phloem surface and included the phloem of both pieces in their tunnelling. The curvature of the pieces allowed freedom of larval movement without penetration of the stone layer and the grubs selected phloem alone, on which complete development was satisfactory.

Development of larvae established in the moist cortical tissue under the outer bark was much slower than that of those in the phloem, and in no instance was growth completed in this tissue alone. Most larvae died in the second or third instar, while a few penetrated a thin part of the stone layer into the phloem. On living trees in the plantation, the phloem about the stub bases of pruned branches is usually sufficiently thick to enable a grub to complete its development in this tissue alone, and tunnelling for any appreciable distance is unnecessary unless competition between grubs enforces it.

Larvae in the trunks of hoop pine thinnings tunnel in much the same manner as those in the living trees. The butt ends are heavily infested and often many larvae may be working closely together, though never in a common tunnel. In *Pinus* spp., the bark is comparatively thin and has no definite sclerenchymatous layer. Hence, during the greater part of their lives, the larvae occupy the whole depth between the cork and the sapwood. In the plantation, as in the laboratory, a noticeable larval characteristic in the tissue of these hosts, more especially in *Pinus radiata,* is the rapid rate of tunnelling; often the total distance extends to 15 inches.

Tunnelling in the stumps of hoop pine thinnings is somewhat comparable to that on the butt, although a copious gum exudate collecting in the cavity between the bark and the wood and in the downwardly extending tunnels often interferes with larval development. In *Pinus radiata* stumps, tunnelling may extend down the main roots, and both larvae and cocoons were often located six inches below ground level.

The phloem of mature hoop pine trees in the scrub is usually so thick that pine bark weevil larvae established in logging residues are provided with an abundance of readily available food, and tunnelling extends only in an irregular field about the point of entry of the young grub.

Larval Survival in the Plantation.

An indication of the rate at which the Aesiotes population increases in the plantation was obtained by recording the number of larvae present under the bark of stems and stumps after the trees had been felled as thinnings. Normally the branches are slashed from the stems, thus providing abundant breeding sites. Frequently, over a hundred larvae were found in one tree. In the extreme case 177 larvae—166 from the stem and 11 from the stump—were collected from a tree 32 feet in length. It was impossible to record egg-laying on the stem, but the number of eggs must have been several times greater than that of the larvae recovered. A stump 2½ inches in diameter and 6 inches in height had 82 eggs laid on the cut surface and 25 larvae were later secured when the bark was peeled away. The butt of the stem from this stump had 24 eggs laid on it and 17 larvae were recovered. Similar butts had as many as eight cocoons. Stumps five to six inches in diameter often harboured 25 to 30 larvae each, while on similar stumps more than 10 cocoons were seldom found. It is possible, therefore, that survival did not exceed 10 per cent. of the eggs laid. Larval development is more frequently completed in the stem than in the stump; however, when the bark of thinnings decays or dries rapidly, a process accelerated by other tunnelling insects, larval mortality is high.

Larval Life History.

Several hundred larvae were bred to the adult stage in blocks in the laboratory, and the following periods for the duration of the larval life in days were recorded:—

	Females.	Males.
Minimum	39	42
Maximum	82	81
Mean	58·9	61·5

These figures show that the mean larval period for the sexes is very similar, and that the range of variation is approximately the same in each case.

Table 5.

PERIODS OF LARVAL INSTARS IN THE LABORATORY (IN DAYS).

February–April 1937.

Lab. No.	Instar.						
	First.	Second.	Third.	Fourth.	Fifth.	Sixth.	Total.
	FIVE INSTARS.						
Females—							
L.381	5	5	4	6	25	..	45
L.411	5	4	4	6	36	..	55
L.419	4	4	5	5	35	..	53
Mean	4·7	4·3	4·3	5·7	32	..	51
Males—							
L.386	5	4	6	8	25	..	48
L.415	3	5	5	6	31	..	50
L.426	3	4	5	6	43	..	61
L.429	3	4	4	6	35	..	52
Mean	3·5	4·2	4·0	6·5	33·5	..	52·7
Mean—Both sexes	4·0	4·3	4·7	6·1	32·9	..	52·0
	SIX INSTARS.						
Females—							
L.380	6	5	6	8	8	24	57
L.394	4	4	5	6	10	30	59
L.407	5	5	5	8	9	21	53
L.413	4	4	5	5	8	32	58
L.416	4	4	4	5	10	27	54
L.425	3	3	4	4	8	37	59
L.427	4	4	4	7	7	37	63
L.430	3	4	4	5	9	34	59
Mean	4·1	4·1	4·6	6·0	8·6	30·2	57·7
Males—							
L.382	6	7	7	7	8	21	57
L.383	5	5	5	7	9	27	58
L.385	5	5	6	9	8	20	53
L.388	6	6	6	8	9	20	55
L.392	5	5	5	8	8	21	52
L.420	4	5	5	5	7	31	57
L.421	4	5	5	5	8	36	63
Mean	5·0	5·4	5·6	7·0	8·1	25·1	56·4
Mean—Both sexes	4·5	4·7	5·1	6·5	8·4	27·9	57·0

The data later obtained from daily examination of breeding material in the laboratory show that the pine bark weevil has a variable number of larval instars, development being completed in either five or six stages (Table 5). Somewhat comparable periods were required for the first four stages in each case. The period of the fifth instar in the one case exceeds that of the sixth in the other, but the inclusion of an additional stage in the six instar insects gives them a greater total larval period. These variations could not be correlated with food or sex. Larvae from eggs laid by one female on the same day and fed on similar food displayed the variation in the number of instars.

The Application of Dyar's Law.

Dyar (1890), working on lepidopterous larvae, found a constant numerical ratio between the head capsule measurements of successive stages and, therefore, the measurements of the head capsules of all the instars form part of a geometrical series. Consequently, with a knowledge of the measurements of the head capsule of the first, last and any two successive stages of any individual, the total number of instars could be determined. This law has been widely applied in lepidopterous life-history studies and more recently it has been used in the study of coleopterous larvae. Andrewartha (1933) showed that Dyar's Law is applicable to the weevil *Otiorrhynchus cribricollis* Fab., and pointed out

Table 6.

Larval Head Capsule Measurements (in mm.).

Larvae with Five Instars.

Lab. No.	Instar.				
	First.	Second.	Third.	Fourth.	Fifth.
L.251	..	..	..	2·10	2·60
L.252	..	..	..	2·00	2·50
L.341	..	0·80	1·40	2·00	2·50
L.343	..	0·80	1·25	1·75	2·40
L.357	0·55	0·75	1·25	1·90	2·75
L.364	0·45	0·70	1·25	1·75	2·40
L.366	0·50	0·75	1·25	1·70	2·40
L.367	..	0·80	1·30	1·85	2·75
L.386	0·55	0·90	1·40	1·85	2·40
L.415	0·40	0·85	1·25	1·75	2·50
L.426	0·50	0·75	1·25	1·75	2·50
L.429	0·50	0·80	1·30	1·80	2·70
L.381	0·50	0·85	1·25	1·75	2·50
L.411	0·40	0·85	1·30	1·80	2·30
L.419	0·45	0·80	1·25	1·75	2·30
Minimum	0·40	0·70	1·25	1·70	2·30
Maximum	0·55	0·90	1·40	2·10	2·75
Mean	0·48	0·80	1·28	1·83	2·50
Ratio		1·67	1·60	1·43	1·31

Table 7.

LARVAL HEAD CAPSULE MEASUREMENTS (in mm.).

Larvae with Six Instars.

Lab. No.	Instar.					
	First.	Second.	Third.	Fourth.	Fifth.	Sixth.
L.183	..	..	..	1·80	2·10	2·80
L.249	..	..	1·30	1·70	2·10	2·80
L.342	..	..	1·25	1·75	2·30	2·80
L.344	..	0·75	1·25	1·70	2·15	2·90
L.349	0·50	0·80	1·25	1·75	2·30	3·00
L.351	0·50	0·80	1·20	1·60	2·10	2·80
L.355	0·50	0·85	1·20	1·60	2·25	2·80
L.380	0·50	0·90	1·25	1·75	2·30	3·00
L.394	0·45	0·75	1·05	1·50	2·10	2·70
L.407	0·50	0·90	1·20	1·75	2·20	2·90
L.413	0·40	0·80	1·20	1·70	2·30	3·00
L.416	0·40	0·80	1·00	1·60	2·25	3·00
L.425	0·45	0·75	1·25	1·65	2·25	3·00
L.427	0·45	0·70	1·20	1·70	2·40	3·00
L.430	0·50	0·80	1·25	1·80	2·40	3·00
L.382	0·50	0·80	1·20	1·55	2·20	2·75
L.383	0·55	0·80	1·25	1·80	2·40	3·10
L.385	0·50	0·85	1·20	1·60	2·00	2·75
L.388	0·50	0·90	1·25	1·70	2·25	3·00
L.392	0·50	0·80	1·20	1·60	2·00	2·90
L.420	0·50	0·86	1·25	1·70	2·30	3·00
L.421	0·50	0·70	1·10	1·60	2·00	2·90
L.401	0·40	0·70	0·85	1·20	1·70	2·30
L.404	0·45	0·70	1·05	1·40	2·00	2·40
Minimum	0·40	0·70	0·85	1·20	1·70	2·30
Maximum	0·55	0·90	1·30	1·80	2·40	3·10
Mean	0·48	0·80	1·18	1·69	2·18	2·86
Ratio		1·67	1·48	1·43	1·29	1·31

that the law is still valid when applied to the mean measurement of successive stages of a number of individuals. Larvae of *Otiorrhynchus cribricollis* are soil-inhabiting and cannot be continuously handled or observed during life-history studies. However, following the application of Dyar's Law to such an insect, it was concluded that "we now have a reliable method for determining the number of instars in the life of soil-inhabiting, leaf-mining and other inaccessible larvae." The pine bark weevil is an insect of this category and attempts were made to apply the law to it; however, rather inconsistent results were obtained. Head capsule measurements from a series of larvae with five stages (Table 6) gave successive ratios of 1·67, 1·60, 1·43, and 1·31, and a series with six instars (Table 7) gave ratios of 1·67, 1.48, 1·43, 1·29, and 1·31. The differences between these ratios are too great for the satisfactory application of Dyar's law to this insect.

TABLE 8.

Larval Frons Measurements (in mm.).

—	Instar.					
	First.	Second.	Third.	Fourth.	Fifth.	Sixth.
	Larvae with Five Instars.					
Minimum	0·37	0·56	0·81	1·13	1·62	..
Maximum	0·45	0·66	0·93	1·27	1·79	..
Mean	0·40	0·59	0·86	1·24	1·70	..
Ratio	1·48	1·46	1·46	1·37	..	
	Larvae with Six Instars					
Minimum	0·35	0·51	0·69	1·01	1·39	1·73
Maximum	0·45	0·64	0·91	1·23	1·66	2·13
Mean	0·41	0·58	0·83	1·15	1·52	1·92
Ratio	1·41	1·43	1·39	1·33	1·26	

TABLE 9.

Larval Labrum Measurements (in mm.).

—	Instar.					
	First.	Second.	Third.	Fourth.	Fifth.	Sixth.
	Larvae with Five Instars.					
Minimum	0·11	0·19	0·26	0·36	0·45	..
Maximum	0·13	0·20	0·28	0·38	0·51	..
Mean	0·12	0·20	0·27	0·37	0·48	..
Ratio	1·67	1·35	1·37	1·30		
	Larvae with Six Instars.					
Minimum	0·11	0·16	0·22	0·30	0·39	0·51
Maximum	0·13	0·19	0·28	0·37	0·57	0·66
Mean	0·12	0·18	0·25	0·34	0·45	0·57
Ratio	1·5	1·39	1·36	1·32	1·27	

On the assumption that Dyar's Law should hold for other rigid and constant structures on insect larvae as well as for the head capsule, McDougall (1934), working on wireworms, based his conclusions on the ventral mouth parts and found that a satisfactory index to the larval instars was obtained. Measurements of various structures on Aesiotes other than the head capsule were therefore made to obtain reliable data. The ventral mouth parts, however, are not very rigid, so the frons (Table 8) and the labrum (Table 9) were measured. The measurements proved more consistent with the underlying theory of Dyar's

Law than did those of the head capsule. Nevertheless, the variation in the ratios between successive instars is still considerable. From the evidence given, it would appear that Dyar's Law may not have general application, especially when a variable number of instars occurs.

Later Larval Habits and Prepupation.

The larva becomes full-grown about 14 days before the transformation into a pupa. By the time feeding has ceased the cavity at the head of the tunnel is oval in shape, about an inch-and-a-half long and almost an inch wide, thus allowing the larva ample space for tearing away the strips of wood to be used in the preparation of the "cocoon" overlying the pupal chamber.

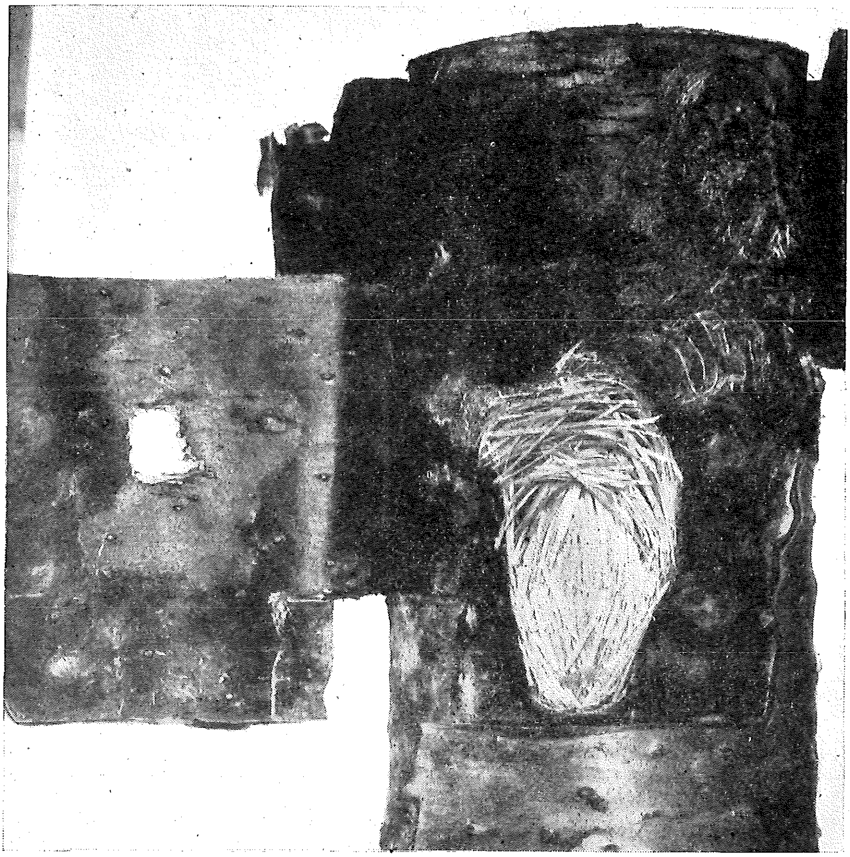

Plate 17.

Cocoon of the pine bark weevil in a hoop pine breeding block with the bark peeled away.

The larva, while lying more or less longitudinally in the cavity, makes a transverse cut into the surface of the wood towards one end of the cavity. It then grasps the inner side of the cut in its mandibles and, by slightly turning the head sideways, raises a thin strip of wood. A fresh grasp and sideways head motion raise the strip further. Repeating these actions, the grub peels a thin strip of wood, 1·0 mm. to 1·5 mm. in width, longitudinally from the surface of the wood for about one-and-a-half times its own length and pushes it aside. Meanwhile the grub has reversed its position and commences to peel the next strip from the other end. Considerable force is required to tear away these strips, and indentations of the mandibles from about 0·5 mm. to 1·0 mm. apart are left on them. If the larval cavity is small the strips may be merely pushed to one side at the free end, but should the cavity be large, as is usual, they are severed at both ends before being pushed aside. The stripping proceeds alternately from end to end. By the second day the grub is located in a small excavation surrounded by wood strips, and by the third day it is almost covered by them.

Eventually these strips fill the cavity above the larva, which now lies in a boat-shaped excavation. Progressively narrower and shorter strips are removed; these are severed at one end only, the oppositely pointing free ends overlapping as they are pushed aside. In the final stages of preparation of the cocoon, very small strips or fibres are scraped away from the base of the excavation. These also are pushed aside and moulded by the grub into a soft, smooth lining for the oval-shaped pupal chamber.

The measurements of the cocoon (Plate 17) depend on the size of the larval cavity in the bark and bear no consistent relationship to the size of the grub. However, the size of the boat-shaped excavation is more directly proportional to that of the grub. The cocoon and the excavation have been measured on both plantation trees and experimental blocks in the laboratory. In the former case, the cocoon averaged 34·0 mm. in length and 20·3 mm. in width, while the excavation averaged 30·1 mm. in length, 7·8 mm. in width and 8·0 mm. in depth. The laboratory data differ from that gathered in the plantation, due no doubt to the frequent disturbances of the insects during observations. Larvae which had practically completed the construction of the cocoon showed little or no response to slight disturbances, but larvae disturbed shortly after constructional work began almost invariably excavated more deeply than usual into the wood—in an extreme case to a depth of 25 mm.

Numerous strips of wood are peeled away during the formation of the cocoon. In two apparently normal cocoons, the following figures were obtained for strips greater than one-quarter-of-an-inch in length:—

(*a*) Free, 911; fixed at one end, 45; total, 956;

(*b*) Free, 653; fixed at one end, 72; total, 725.

Of these, 10 per cent. were greater than one inch in length, about 50 per cent. were less than one inch but greater than half-an-inch in length, and the remaining 40 per cent. were less than half-an-inch in length.

A period of inactivity follows the final smoothing of the pupal chamber lining. The larva first extends itself lengthwise, then very gradually shrinks, and equally slowly the head and thorax become ventrally inclined, until they are almost at right angles to the remainder of the body. By this time the grub is noticeably smaller and has a wrinkled skin. A slight enlargement appears dorsally on the prothorax, where the larval skin soon ruptures, revealing the anterior portion of the pupa. The exuvium is then gradually worked back along the body and is shed at the posterior end.

The period spent by the larvae in tunnelling through the bark, as determined from 24 individuals with a mean larval period of 62·6 days, averaged 48·4 days, or just less than four-fifths of their life. The minimum tunnelling period recorded was 26·0 days, which was two-thirds of that particular larval period. The time elapsing between the cessation of tunnelling and pupation averaged 14·5 days or just over one-fifth of the total larval period. Of this period, however, about 8·0 days were spent in constructing the cocoon and pupal chamber and 6·5 days in the quiescent prepupal state.

Establishment of Larvae in Silky Oak.

Confirmation of French's record of silky oak, *Grevillea robusta,* as a host of the pine bark weevil was not obtained in the field. In laboratory tests, newly emerged larvae were inserted under the bark on blocks of green silky oak, but no feeding of any consequence took place except in one block in which two of the larvae tunnelled for two inches before dying. Observations made fortnightly after the insertion of the larvae showed that, in spite of adequate end-sealing, the bark on the blocks might have been too dry to sustain the larvae. As more regular supplies of fresh silky oak could not be maintained for laboratory work, attempts were made to establish larvae in trees in the field.

Two methods were adopted, viz. (1), inserting larvae into the cambial region of living trees; and (2), inserting larvae into the cambial region of recently felled trees. In both cases mostly second-stage, but also some third-stage, larvae were placed in freshly-made cuts on pruned stubs and on the tree trunks. Some larvae were unable to initiate burrows before being attacked by the green-head ant, *Chalcoponera metallica* Sm. However, a number immediately tore away threads of the inner bark and found shelter. During the ensuing five weeks, similar larvae in adjacent hoop pine thinnings progressed from the second to the last larval stage. In the silky oak, however, all larvae died and only a few had attempted to continue tunnelling. The longest distance tunnelled by any grub was one-and-a-quarter inches. Both of the foregoing experiments were repeated, with almost identical results. Actually, the portion of infested silky oak log illustrated by French rather resembles kauri pine, which is a natural host. From the evidence given, it must be concluded that the possibility of silky oak functioning as a host for the pine bark weevil is remote.

The Pupa.

Orientation of the Pupa.

In logging residues in the scrub, where food is abundant, larval feeding does not extend far from the point of entry and pupation normally occurs in close proximity to that point with the head directed back towards the cut surface.

This pupal disposition is general, irrespective of the place of larval entry, and no doubt facilitates adult emergence. A similar orientation is shown on trees and thinnings in the plantation, but the grubs may tunnel some distance from the point of entry, and inconsistencies then occur.

On stumps of thinnings in the plantation the head of the pupa invariably is directed upwards towards the cut surface where the larva enters. In the laboratory, grubs established on the top end of blocks with a moderately thick bark pupated with the head upwards and those established on the lower end had the pupal head pointing downwards. Even when the ends were reversed during larval development, the head of the pupa always pointed back in the direction of the point of entry. Inconsistencies occurred in thin-barked blocks, when the depth of the larval tunnel reached to, or almost to, the outer bark.

Pupal History.

Like that of most other insects, the pupa of Aesiotes is quiescent, though it can revolve in the pupal chamber. Disturbance, even if effected by sharp jarring of experimental blocks, does not affect the pupa, probably because it is armed with stout spines on cushion-like bases which protect it against shock.

There is no noticeable change in the appearance of the pupa on the day following transformation from the larva. The following changes were observed in particular individuals. On the second day, minute, dark spots are discernible on the white background towards the posterior region of the eye surface. These spots are the embryonic facets of the eye. On the third day, the spotted area extends for one-third of the distance across the eye and the first spots to appear have become larger. On the fourth day, the dark spots have spread for two-thirds of the distance across the eye; while on the fifth the facets are discernible over the whole eye surface. Those first to appear are now faint-brown in colour. For a few days, the eye colour gradually deepens from pale-brown to dark-brown, and by the eighth day is a blue-black colour. In the meantime, the dots of colour have individually enlarged and finally coalesced, and the dark colour covers the whole eye. On the ninth day a faint colour is apparent in the region of the mandibles. This rapidly darkens, and by the eleventh day it is dark-brown, especially on the serrated tips of the mandibles. Also on the eleventh day a faint colour is apparent on the knees, while on the twelfth day a faint darkening in the creamy ground colour of the elytra and prothorax is perceptible, more especially on the protuberances. These have darkened appreciably by the next day, when the general body colour has become suffused with a creamy to dusky pale-brown. Emergence of the adult might occur on the fourteenth day or, following an intensification of the body colour, on the fifteenth day.

A representative series of individuals bred through the pupal stage showed a minimum pupal period of 11 days, and a maximum of 15 days, with a mean of 13·4 days.

The Adult.

Adult Emergence.

The adult is very fragile at first and remains quiescent within the pupal chamber for almost two weeks before it escapes. It then draws away the cell lining and bites its way through the strips of wood composing the cocoon (Plate 18). Eventually a more or less round hole is eaten through the overlying tissues and the hard bark to the exterior. While in the cocoon the adult is initially a pale bronze colour, which gradually darkens through bronze to a brownish-grey.

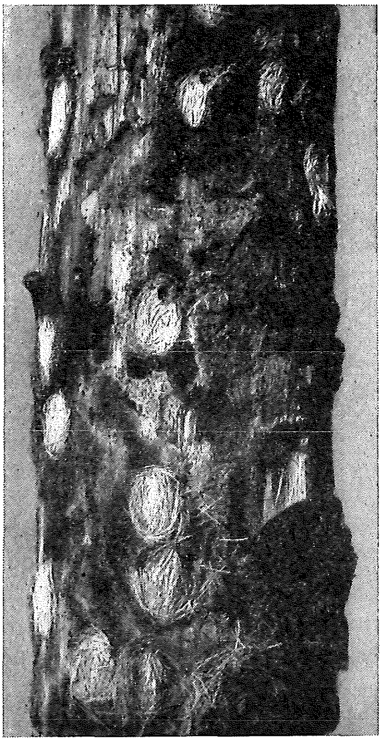

Plate 18.

Hoop pine stem with bark removed, showing pine bark weevil cocoons. Note emergence holes.

The period elapsing between transformation to the adult and emergence from the pupal chamber showed considerable variation, ranging from five to 19 days for males and from eight to 19 days for females. However, the difference between the respective means of 12·5 and 11·3 days is slight.

Habits of the Adult.

Adults in the field prefer dark or shaded positions during the daytime and, on thinnings, occur almost invariably on the lower or shaded side of the bole or under cover of the branches. Those found about the stumps are under pieces of loose bark, mostly on the shaded side, or in debris on the ground. Occasionally a few adults are located on the trunks of living trees, but always under pieces of loose bark or in depressions. On overcast days they may sometimes be located in more exposed positions.

Negative phototropism was also apparent in the laboratory. When tubes containing pairs of adults were placed in a well-lit position, as occurred during feeding operations, the beetles of both sexes immediately sought the shadow of the piece of bark within the tube. When liberated in well-lit situations in the laboratory the beetles, even though near a piece of fresh hoop pine bark, would walk about until a dark position was reached.

Plate 19.

Tripod with suspended piece of hoop pine erected in plantation for investigation of flight by the pine bark weevil.

The pine bark weevil can feign death very well, but does not assume the compact form of the Cryptorhynchinae. Although the appendages become rigid, the insect can quickly clasp any object encountered in falling. Immobility may be maintained for only a brief period if the beetle falls into a sheltered position, but beetles falling into an exposed place remain quiescent for long periods; sometimes one-and-a-half hours elapse before activity is resumed. It was not unusual for weevils placed on their backs in exposed places in the laboratory to remain so for periods of an hour or more. Often the return to the normal posture is gradual and almost imperceptible.

Weevils generally are not active fliers, and although the pine bark weevil has well developed wings flight has been seen once only, when a beetle flew from the laboratory bench to the window. However, flight does occur, because many eggs were laid on freshly-cut hoop pine tree trunk sections, suitably buffered and suspended from tripods in the plantation (Plate 19) as well as in the natural rain forest. In 27 out of 30 instances, eggs were laid on the suspended pieces. Double sections with another buffer between them each had eggs laid on them. These tree sections could be reached only by insects on the wing; therefore, flight by the pine bark weevil, if not a normal characteristic, must be fairly common. Additional evidence of flight by this weevil is provided by the fact that tanglefoot bands placed above and below the green stubs on pruned trees do not prevent egg-laying on the freshly-cut surfaces.

The Distribution of Adults in the Plantation.

Land in the course of preparation for hoop pine plantations is swept by a fierce fire before restocking with young pine trees is begun, and the whole pine bark weevil population then present must be completely annihilated. Reoccupation of these areas must, therefore, be the result of dispersion from outside sources. To determine adult movements, 36 adults were marked with a quick-drying enamel paint and liberated in a plantation. During the subsequent four months, 18 of these beetles were recovered. They were located in various directions at distances from one to five chains from the site of liberation. One of these beetles, recovered a month after release, had crossed first a gully, then a spur, and finally a second gully to reach the position where it was found. Flight seems the only probable explanation of the data, and suggests that dispersion over considerable distances might not be uncommon. This would explain the occurrence of beetles in localities far removed from natural breeding centres.

A positive relationship exists between moisture and the apparent adult population in plantations, and this is also reflected in adult activity; the response to rainfall is particularly noticeable after periods of dry weather. Invariably adults are more numerous in or near moist locations in hollows and gullies than on the drier spurs. On one occasion during dry weather, observations for three days following some routine thinning revealed no sign of egg-laying or even of adults on a spur, while at the same time both eggs and adults were present, although not common, in the hollows. A shower of rain fell during the third evening. On the following day, the number of additional adults collected in hollows had increased 10 times and the number of eggs 20 times, while on the spur both adults and eggs were common. Weather conditions, therefore, exercise an important influence on estimates of pine bark weevil populations in plantations.

Unmerchantable thinnings normally have all branches slashed off and the stem cut through in several places, thus providing a large number of cut surfaces attractive to the pine bark weevil. No difficulty was experienced in collecting weevils about stumps, but unavoidable disturbances along the stems and branches caused some of the insects to fall amongst the slash and ground litter, where possibly they escaped detection. Adults would also be normally dispersed amongst the slash which could not be conveniently searched. Actual collections, therefore, probably underestimate the total number of adults present. In April, 1937, 10 plantation trees scattered over two-thirds of an acre in a moist hollow, and six trees over one-third of an acre on a spur, were felled and adults were collected about them on each of the following eight days (Table 10). A total of 321 beetles was secured, 258, or a mean of 25·8 per tree, in the moist location and 63, or a mean of 10·5 per tree, in the drier one. Though such a collection is unlikely to have exhausted the adult population within the areas, it

Table 10.

ADULT DENSITY IN THE PLANTATION.

Counts from 16 Trees Felled 15–4–37.

Date.	16th.	17th.	18th.	19th.	20th.	21st.	22nd.	23rd.	Total.
TREES IN MOIST LOCATION.									
A	6	5	2	3	1	3	2	0	22
B	4	10	7	1	1	3	6	2	34
C	6	12	5	5	2	0	0	0	30
D	3	4	5	3	2	0	1	1	19
E	1	1	1	3	1	2	0	0	9
F	0	2	1	1	0	0	0	0	4
G	5	8	3	2	2	3	2	0	25
H	6	12	10	4	9	1	3	2	47
I	6	7	8	6	2	1	0	1	31
J	6	5	2	7	6	6	3	2	37
Total ..	43	66	44	35	26	19	17	8	258
Mean per Tree ..	4·3	6·6	4·4	3·5	2·6	1·9	1·7	0·8	25·8
TREES IN DRY LOCATION.									
K	1	0	1	4	0	0	2	3	11
L	4	2	2	1	1	4	0	1	15
M	1	2	1	1	2	0	0	0	7
N	4	1	1	7	1	1	0	0	15
O	4	1	1	0	1	1	0	0	8
P	4	1	0	0	0	1	1	0	7
Total ..	18	7	6	13	5	7	3	4	63
Mean per Tree ..	3·0	1·2	1·0	2·2	0·8	1·2	0·5	0·7	10·5
Aggregate	61	73	50	48	31	26	20	12	321
Mean per Tree ..	3·8	4·6	3·1	3·0	1·9	1·6	1·25	0·75	20·1

should indicate the relative abundance. A correct estimate of the radius of attraction of a freshly felled tree could not be obtained. It is conceivable that the sixteen felled trees caused an influx of beetles from the surrounding area. However, check fellings outside the test area showed that adults were still numerous there. The attractiveness of thinnings is greatest on the second day following felling and decreases steadily for a week, when it drops sharply.

Further trees were then felled and these yielded a comparatively large number of additional beetles. On another occasion, when beetles could no longer be found, the stems were once more slashed and adults were again numerous on the following day, though in smaller numbers than on freshly felled trees outside the test area.

Seasonal Abundance of Adults.

Commencing in October, 1936, and continuing until June, 1938, three nearby plantation trees were felled each month for records of seasonal abundance of adults. As the greatest attraction to the trees occurs during the first few days, weevil counts were made on all occasions on the third day following felling. These counts may be taken as an index of seasonal activity (Figure 2), and the data obtained when correlated with weather conditions (as shown in Figure 1) show a positive relationship with rainfall.

In the comparatively dry month of October, 1936, the adult population was very low, the mean number per tree being only 0·7. An increase in rainfall through November to December was accompanied by an increase in population to 3·7 adults per tree. Low rainfall in January, 1937, reduced the adults again to 0·7 per tree. However, the high rainfall in February and March and the carry-over of moisture into April produced in April a peak in adult density—14·3 adults per tree. Declining moisture as winter approached apparently limited pine bark weevil abundance in the dry months of June and July, but showers in August were associated with some activity. Adult numbers then receded to a mean minimum of 0·3 per tree in October, 1937, a month which was, however, comparatively wet. Possibly some unrecorded adverse factor was operating at this time. The wet months of November and December were accompanied by an increase in the number of adults, but not in the proportion expected. However, in the wet month of January, 1938, the huge peak of 40 adults per tree was reached, only to decline again in succeeding months with a decline in rainfall.

Elsewhere it is shown that pine bark weevils can live for periods exceeding 12 months. It is probable, therefore, that the adult population in the plantation is high and relatively constant throughout the whole year and that the apparent population as shown reflects not numerical abundance but activity, which is determined by moisture rather than temperature, though the latter may have an indirect influence.

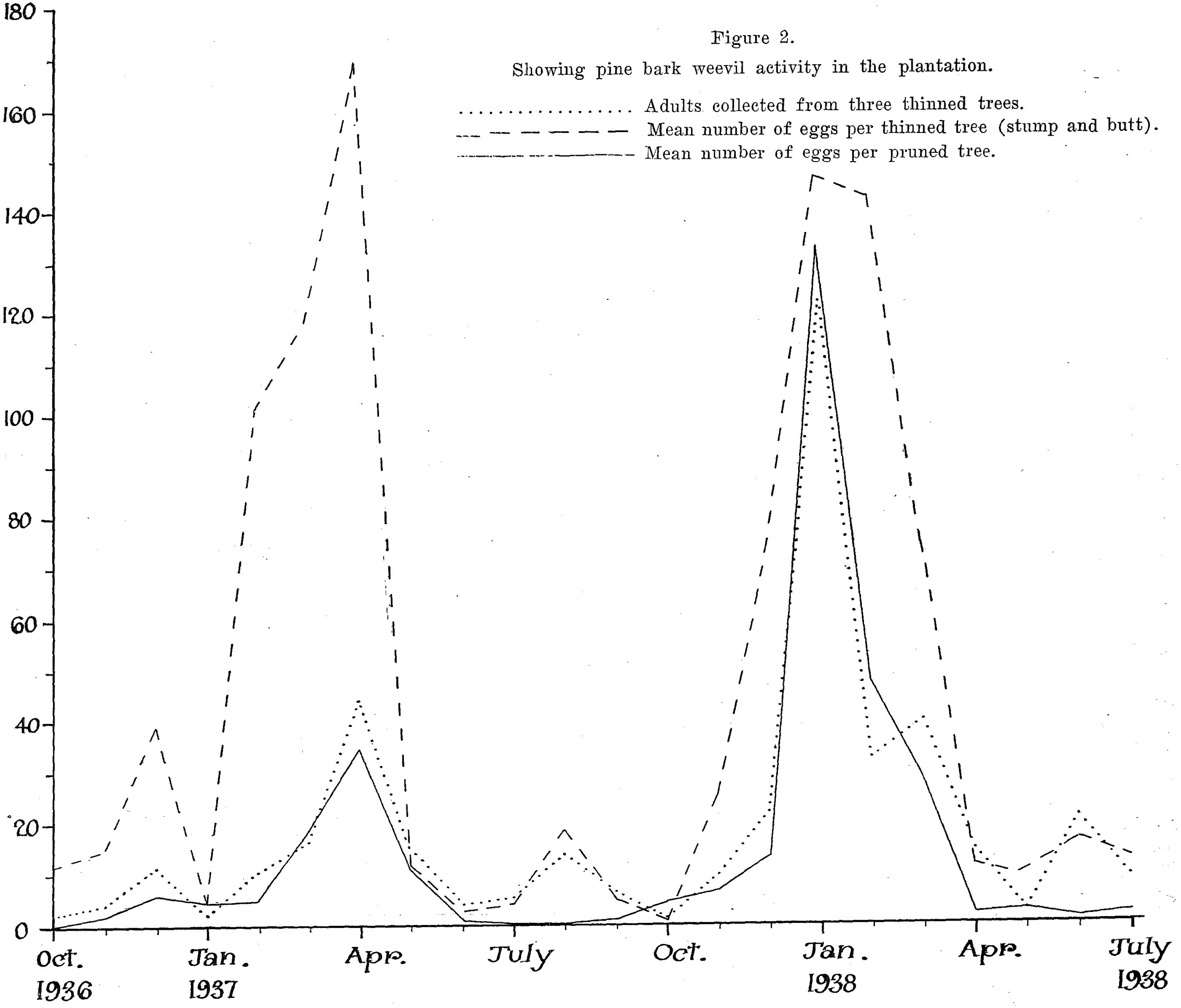

Figure 2.

Showing pine bark weevil activity in the plantation.

Adult Feeding and Feeding Preference.

The food supplied to adults in the laboratory consisted of fresh hoop pine bark from which the outer, parchment-like cork layer had been peeled. Feeding injury, resembling rough surface erosion, occurred on both the phloem (Plate 20) and cortex. The degree of erosion was often unequally disposed on these two sides of the bark and preferences for one or the other were, therefore, investigated. Feeding is mainly a nocturnal habit, so the insects were kept in darkness. Fresh food was supplied each day, phloem and cortex being placed uppermost on alternate days. During these short periods, feeding frequently occurred on one side only or was greater on one side than the other. Although the beetles fed mostly on the uppermost surface they showed a distinct preference for the cortex. When fresh food was supplied to beetles which had not been fed for some days the phloem was first attacked, but after a few hours and during succeeding days feeding was frequently restricted to the cortex. This characteristic may bear a relationship to the moisture content of the two tissues, for the phloem, though very moist when freshly peeled from the tree section, dries more rapidly than the cortex.

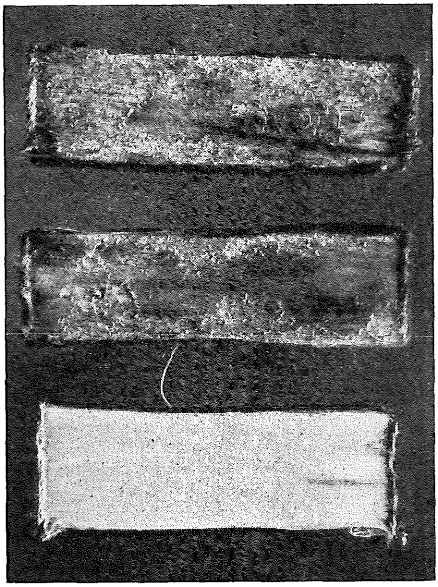

Plate 20.

Hoop pine bark on the phloem of which pine bark weevil adults have fed. A fresh piece of bark is shown as a contrast.

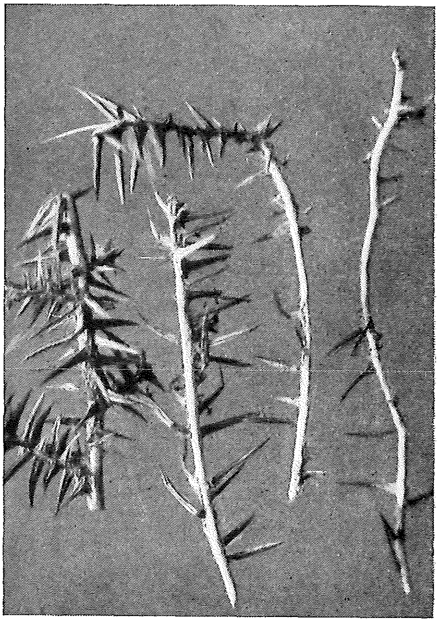

Plate 21.

Hoop pine foliage on which pine bark weevil adults have fed.

The amount of feeding observed in the plantation was on no occasion as extensive as in the laboratory, where pairs of beetles would erode one square inch of bark surface in 24 hours. Further, the cork layer does not readily separate from the cortex and feeding, therefore, occurs mainly on phloem which has lifted away from the wood. Beetles may feed on tissues other than the injured bark of the tree trunk, as might be expected from their occurrence in plantations free from slash. In the laboratory, beetles fed freely on hoop pine foliage when provided with this material alone (Plate 21). They also fed on the intact bark of young shoots and even ate away the bark from branches up to half-an-inch in diameter. Similar feeding occurred on bunya pine, kauri pine and species of *Pinus*. Erosion observed on branches of plantation trees was probably caused by this insect. Beetles confined on seedlings of kauri pine and hoop pine about one foot in height completely girdled the stems and thus killed the upper portions of the plants.

Attraction to Injured Hoop Pine Bark.

The relative importance of the several layers of bark tissue in attracting pine bark weevils to hoop pine was determined by observations on their behaviour on trees treated by—

(*a*) Peeling the outer, parchment-like sheet of cork tissue from the bark and thus exposing the fleshy cortex;

(*b*) Rasping off both cork and cortical tissue to the sclerenchymatous layer;

(*c*) Rasping off the cork, cortical and sclerenchymatous tissues to expose the phloem; and

(*d*) Peeling away the whole bark and exposing the sapwood.

No oviposition took place on trees treated as in (*a*). On trees treated as in (*b*) there were very few eggs laid, while on trees of treatments (*c*) and (*d*) oviposition was of almost equal intensity and moderately heavy. Larval establishment occurred only on trees with the phloem or the sapwood exposed. In the latter case, the larvae entered the cut bark where the exudation was least; entrance through the phloem took place only after splitting had occurred.

Resin canals in the outer phloem are few in number and, therefore, little or no exudation appeared on trees subjected to the first two treatments. In the remainder, however, a copious gum flow issued from the injured tissues. It is possible that volatile substances issuing from the bark, the wood or the exudate attract the weevils to freshly wounded tissue. Little is known concerning the chemical composition of the bark or wood of the native hosts of the pine bark weevil, but the exudate has been the subject of investigations by Baker and Smith (1910), who showed that volatile constituents are present in appreciable quantities.

The exudations from hoop, bunya, and kauri pines are at first milky-white due to resin in suspension, but later they darken in colour. The following analyses are from Baker and Smith (1910):—

	Hoop Pine. %	Southern Kauri Pine. %
Volatile oil	3·800	11·64
Volatile acids (calculated as acetic acid)	0·134	0·1055
Gum	8·000	2·37
Reducing sugars	—	0·62
Resin	47·000	62·00
Nitrogenous residue	0·510	0·20
Woody residue	0·600	—
Water and undetermined constituents, by difference	39·956	23·064

The volatile oil in hoop pine exudate is an undetermined hydrocarbon of the terpene series. The volatile portion of southern kauri pine "oleo-resin" is pinene, a monocyclic terpene. Birch (1937), working on the volatile portion of bunya pine exudate, isolated d-limonene, which is also a monocyclic terpene and closely related to pinene. The volatile acids (although determined as acetic acid in the analyses) comprise both acetic and butyric acids. In the hoop pine exudate they are present in the proportion of 3:2 and in southern kauri pine almost 3:1.

Further investigations on the chemotropic responses of Aesiotes which might influence the method of control were commenced, but were discontinued when the elimination of economic damage by pruning at a certain time was found possible.

Adult Longevity.

Both field-collected and laboratory-bred beetles were used in the laboratory studies on longevity. The dates of emergence of the former were unknown and in some cases beetles outlived the tests in which they were used. The estimates of longevity, therefore, do not take into account periods of adult life before collection nor periods subsequent to the closure of observations, and are only approximations. For this reason, only those individuals whose life in captivity exceeded nine months are recorded in Table 11.

The longest period for which an adult lived in captivity was 679 days. This individual, a male, was taken from a random collection in the field; and, as the date of emergence was indeterminable, the life span might have been much greater. A period of two weeks elapses between development as an adult and emergence from the cocoon. An interval must also be presumed between emergence and collection in the plantation. Consequently a period of several weeks must be added to that for which the beetles were maintained alive in the laboratory. A total longevity approximating two years is then obtained. Such a long life probably explains the presence of an adult population in the plantations throughout the whole year.

Table 11.

ADULT LONGEVITY IN THE LABORATORY (in days).

Lab. No. of Mated Pair.	Date of Isolation.	Females.		Males.	
		Date of Death.	Longevity.	Date of Death.	Longevity.
FIELD-COLLECTED BEETLES—DATE OF EMERGENCE UNKNOWN.					
ii	10–7–36	..	..	1–5–37	295
iii	10–7–36	1–5–37	295	..	..
v	10–7–36	26–5–37	320	29–6–37	354
xi	10–7–36	..	..	9–4–37	273
xv	20–7–36	30–5–37	314	..	..
xviii	20–7–36	..	..	1–5–37	285
xix	20–7–36	22–12–37	520	..	..
xx	20–7–36	..	..	8–5–37	292
xxii	20–7–36	8–11–37	476	..	..
xxviii	20–7–36	1–5–37	285	..	..
xxxiv	1–9–36	28–6–37	300	..	..
xxxix	2–9–36	..	..	13–7–38	679
xli	2–9–36	..	..	10–7–38	676
xliv	2–9–36	..	..	24–2–38	539
xlv	3–9–36	12–3–38	554	16–8–37	347
lviii	23–2–37	..	..	1–6–38	463
lxii	16–2–37	*	608	..	..
lxiii	16–2–37	..	..	30–4–38	438
48	17–4–37	18–6–38	427	..	..
60	18–4–37	15–7–38	453	..	..
189	20–5–37	1–7–38	407	..	..
297	21–5–37	..	..	*	514
LABORATORY-BRED BEETLES—MATED ON EMERGENCE.					
L.380	1–5–37	21–3–38	317	..	..
L.383	3–5–37	..	..	*	532
L.386	23–4–37	..	..	*	542
L.388	30–4–37	..	..	*	535
L.394	7–5–37	*	528	..	..
L.407	3–5–37	*	532	..	..
L.413	26–5–37	1–6–38	571	..	..
L.415	19–5–37	..	..	*	516
L.419	25–5–37	26–2–38	277	..	..
L.420	29–5–37	..	..	5–9–38	463
L.425	4–6–37	*	500	..	..
L.427	11–6–37	..	..	5–9–38	451
L.430	6–6–37	*	498	..	..

* Still alive on 17–10–38, when observations ceased

The Influence of Food on Longevity.

At the commencement of these investigations, the food requirements of the adults were not completely known. It was presumed that bark constituted the normal food, but the amount of weevil erosion on freshly injured bark surfaces in the plantation was small in comparison with the number of adults generally present. As the cut or injured bark normally used as food by the adults is uncommon in the plantation until thinning or pruning operations commence, adult longevity in the absence of food was determined. Twenty pairs of adults in the laboratory were kept without food in containers provided with moist cotton wool in order to maintain an atmosphere comparable in some respects with that near the ground in the plantation. Adults often were in close contact with the cotton wool as if extracting moisture, but the females lived for a mean period of only 17·9 days and the males for a mean period of 17·1 days.

As adults apparently live for considerable periods, even in unpruned plantations, they must feed on portions of the trees other than wound tissue. Twelve pairs of beetles were, therefore, provided with hoop pine foliage and on this they fed extensively (Plate 21). Their behaviour at first seemed normal, but the females lived for a mean period of only 64·2 days. Two of the 12 males, however, survived the test, which lasted 108 days. Twelve pairs of adults constantly supplied with pieces of fresh bark were used as controls and all of these outlived the experiment. The kind of food consumed by pine bark weevils, therefore, obviously exercises a considerable influence on longevity, and adults must feed on tissues other than hoop pine foliage in order to maintain the large resident population in the plantation. It has been shown that feeding on the bark of small branches can occur. Erosion of this nature is common on branches in the plantations, but as this habit is shared by other weevils, the amount due to pine bark weevil could not be determined.

Sexual Characters.

The external genitalia of the pine bark weevil are not evident in either the pupal or adult stages, and therefore macroscopic sex differentiation cannot be based on such characters. Certain weevils possess small secondary sex differences such as indentations on the abdominal sternites. A large series of adult pine bark weevils was, therefore, separated into two groups according to the presence or absence of an indentation centrally placed on the posterior margin of the first visible abdominal sternite. Usually this indentation is clearly distinguishable, but occasionally it is faint or obscured by the body scales. The value of this character for sex determination was later checked by observing mating adults and carefully examining the remainder of the insects under the binocular microscope. The cloacal region could be prised open to expose the genitalia without any ill-effects on the beetles and in this way accurate sex determinations were made. Correlating actual sex determinations with the presence or absence of an indentation on the abdominal sternite gave the following results:—indented—males 56, females 36; plain—males 34, females

51. These results are too inconsistent to permit the use of the abdominal sternite as a character for sex determination and all subsequent determinations were made by direct cloacal examinations.

The proportion of the sexes in both field-collected and laboratory-bred adults was much the same, males being very slightly in excess in both cases. During field collections, mating occurred shortly after adults were placed in a common container. The segregation of pairs of adults was thus a simple matter and the data obtained in this way, together with actual sex determinations of the unmated insects, yielded the following proportions:—field-collected—females 47·3 per cent., males 52·7 per cent.; laboratory-bred—females 47·9 per cent., males 52·1 per cent.

Adults of the pine bark weevil are both polyandrous and polygamous. Mating readily takes place when males and females are grouped together, and during field collections in April and May, 1937, 360 pairs out of a possible 362 were separated by this characteristic. There appears to be little, if any, courtship and mating is of the usual curculionid type. Mating normally takes place at night. However, under natural conditions in the plantations it has been recorded in the daytime during overcast weather or in very sheltered positions. In the laboratory, mating commonly followed adult feeding on fresh bark, though other stimuli are probably involved in view of the phenomenon of mass mating which sometimes occurs when adults are collected in the field and placed in a common container without food.

Reproductive Organs.

The reproductive organs dissected from a mature female (Plate 22, fig. 2) about to lay eggs consist of ovarioles, paired oviducts, uterus, bursa copulatrix, receptaculum seminis and accessory gland.

There are four ovarioles, two on each side of the body. They arise from elongate-oval terminal chambers or germinaria (g) which are distally connected in pairs by a terminal filament (tf). The germinarium leads into a long ovarian tube or vitellarium (vt) containing a row of immature eggs. Anteriorly the eggs are small, embryonic bodies which give the tube a segmented appearance. Posteriorly, towards the common junction of the paired tubes and the oviduct, the eggs are almost mature. The short, paired oviducts (ov) contain mature eggs and unite to form a common tube, the uterus (ut). On the dorsal side, the uterus enlarges into a sac, the bursa copulatrix. Entering at the junction of the uterus and the bursa copulatrix is a slender tube from the small accessory gland (ag) and the hook-shaped, chitinous receptaculum seminis (rs). Ventrally and posteriorly from the bursa copulatrix is the vagina (v). Attached by muscles to the ventral surface of the vagina is a chitinous plate, the spiculum ventrale (sv).

The reproductive organs of a mature male (Plate 22, fig. 1) consist of paired testes, vasa deferentia, seminal tubes and accessory glands, an ejaculatory duct and an internal sac.

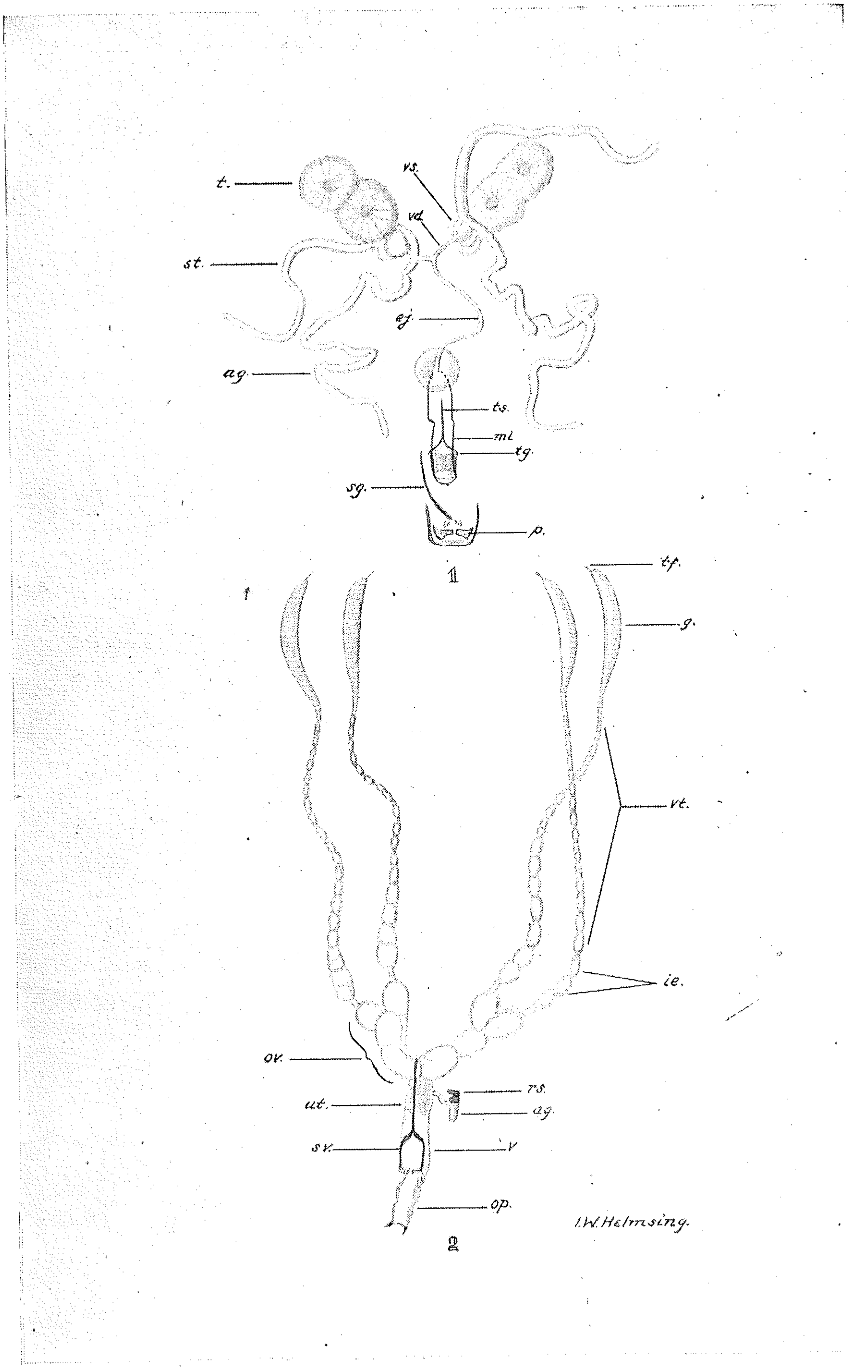

Plate 22.

Reproductive organs of the pine bark weevil. Fig. 1, male; fig. 2, female.

The testes (t) are conspicuous, dorso-ventrally compressed, bilobed bodies situated one on either side of the abdomen. Each lobe is subcircular and consists of numerous follicles. Leading from each posterior lobe is a vas deferens (vd) on which is a lobed vesicular seminalis (vs). Between the testes and seminal vesicle, a seminal tube (st) and an accessory gland (ag) enter the vas deferens on opposite sides. The seminal tube is an elongate structure while the accessory gland, though similar, is much longer and highly convoluted. The ejaculatory duct (ej) is formed by the union of the paired vasa deferentia a short distance from the vesicular seminalis. It is a long, slender tube and posteriorly enters the internal sac. The latter passes forward through the median lobe (ml), terminating at the median orifice. The median lobe is a chitinous tube bluntly pointed at the terminal end. Ensheathing it is a chitinous ring, the tegmen (tg), which is anteriorly produced into a chitinous rod, the tegmenal strut (ts). Lying beneath the median lobe is the spiculum gastrale (sg). Anteriorly it consists of a chitinous rod bent towards the dorsal surface and two small posterior arms. The sternites or genital plates (p) of the eighth segment are flat, triangular and highly chitinized.

Oviposition.

In the laboratory females mated a day after they had emerged from the pupal cocoons. i.e., almost a fortnight after development to the adult stage. At least 15 days then elapsed before egg-laying commenced, and the period sometimes extended to seven weeks. The mean period elapsing between mating and the commencement of oviposition was about three-and-a-half weeks and the average period between attaining the adult stage and oviposition was five-and-a-half weeks. At first very small numbers of eggs were laid at rather irregular intervals, and an oviposition rate approaching the general mean of three eggs a day was not attained until about four weeks later. Over periods of 100 days or more the mean egg-laying rate varied from 1·0 to 4·2 per day.

The females used in determining the period of oviposition were taken from random field collections and were actively laying when collected. The recorded oviposition periods (Table 4) are, therefore, less than the maximum which is possible. For practical purposes, the records available indicate that females may lay fertile eggs for periods greater than one year.

As with most other insects, the female pine bark weevil dies soon after the completion of egg-laying. The period elapsing between the cessation of egg-laying and death for 35 individuals averaged 36·4 days, which is comparatively brief when compared with the total possible life. The minimum period recorded was only six days, while the maximum was 139 days. During this period of senility, mating may take place but such behaviour is doubtless abnormal.

Seasonal Oviposition in the Plantation.

Field observations have shown that the earlier the eggs hatch the greater the probability of larval establishment in fresh wounds. Larvae emerging from eggs laid during the first three days following pruning are, therefore, most likely to become established in the host. By the time larvae have emerged from eggs laid later the wound tissue may be dry and hard and, therefore, difficult to penetrate. For these reasons, the number of eggs laid during the first three days after pruning has been considered a measure of the "effective egg-laying" so far as attacks on pruned trees are concerned. Records of "effective egg-laying" do not represent the total number of eggs laid on pruned trees nor the total period during which adults are attracted to them. The figures are, however, adequate indices of the adult attraction to and egg-laying on the trees.

From October, 1936, to July, 1938, five adjacent trees were pruned each month to a height of about 16 feet and every green stub in each whorl was carefully examined for eggs. During each month, three trees were cut down as thinnings and the eggs laid on the stumps, and butts, of these were recorded. When seasonal oviposition (Figure 2) is compared with the weather data (Figure 1), a relationship is apparent between oviposition and climatic factors, especially rainfall.

Egg-laying in October, 1936, was not very great. Through November it increased to a secondary peak in the wetter month of December, only to fall appreciably in the hot, dry month of January, 1937. Abundant rains in February and March were accompanied by an extremely high rate of oviposition. However, the greatest egg count on both pruned trees and thinnings in this season was obtained in April, a month with a comparatively low rainfall, although heavy rain in March ensured a high humidity in the environment. During the relatively dry winter months of May, June, and July, oviposition was negligible. Showers in August caused some activity, but egg-laying was again low in the dry month of September. Rain in October was not accompanied by increased oviposition, but in the succeeding wet months of November and December, 1937, and January, 1938, egg-laying on pruned trees reached its greatest peak. A high oviposition rate was maintained throughout the moist months of February and March, but declined rapidly in the dry month of April, and remained comparatively low through May, June, and July, although the month of May was moist.

Temperature and moisture are the two most important factors influencing the activities of insects, and if temperatures are favourable to an insect, moisture frequently plays the role of limiting factor. The records of weather data for the plantation show that the range of mean monthly temperatures throughout the year lies well within the limits—18 deg. C. to 28 deg. C.—most favourable to oviposition by the pine bark weevil as shown in the laboratory. Rainfall is a far greater variable than temperature and is accompanied by the major variations of oviposition. It seems, therefore, that rainfall, insofar as it provides a moist environment, is the chief factor governing oviposition in the plantation.

Conversely, if moisture conditions are favourable for oviposition, temperature might be the limiting factor. Records of seasonal oviposition in the laboratory, where moisture conditions were comparatively uniform, showed that seasonal variations in temperature and variations in oviposition rates were concurrent. However, the evidence as a whole shows that the influence of precipitation on oviposition in the plantation is more important than that of temperature.

The Distribution and Rate of Oviposition on Pruned Trees in the Plantation.

During the moist months of February and March, 1938, daily egg counts were made on pruned trees to determine the extent of oviposition beyond the three day "effective egg-laying" period used as an index of oviposition.

The trees in the February test carried from seven to 10 whorls of green stubs—the mean being 8·5—with a mean of five stubs per whorl. Two days after pruning a mean of 27·8 eggs per tree had been laid. This increased to 46·2 eggs per tree on the third day and 162·2 eggs per tree on the fourth day (Table 12).

Table 12.

EGG COUNTS SHOWING DISTRIBUTION AND RATE OF OVIPOSITION ON PRUNED TREES.
(February, 1938).

Day after Pruning.	Tree.	Whorl.										
		Top.	2nd.	3rd.	4th.	5th.	6th.	7th.	8th.	9th.	10th.	Totals.
2nd	A	11	14	16	7	5	5	4	3	3	7	77
	B	12	14	3	3	1	3	2	0	*	*	38
	C	3	1	1	1	0	1	1	*	*	*	8
	D	1	0	0	0	0	0	0	0	0	*	1
	E	3	4	2	2	0	4	0	0	0	*	15
Progress	Total	30	33	22	13	6	13	7	3	3	7	139
3rd	A	$\dot{6}$	16	18	12	5	8	4	4	6	8	88
	B	20	20	10	6	3	7	4	2	*	*	72
	C	8	6	1	3	1	2	4	*	*	*	25
	D	7	1	2	0	0	0	0	0	1	*	11
	E	4	$\dot{3}$	6	2	8	8	1	0	3	*	35
Progress	Total	45	46	37	23	17	25	13	6	10	8	231
4th	A	14	19	22	18	5	$\dot{6}$	7	4	$\dot{4}$	8	107
	B	25	24	$\dot{9}$	8	6	8	8	7	*	*	95
	C	9	$\dot{3}$	2	$\dot{2}$	$\dot{0}$	3	$\dot{0}$	*	*	*	$1\dot{9}$
	D	7	5	7	6	1	6	0	1	$\dot{0}$	*	31
	E	13	4	6	7	$\dot{6}$	$\dot{6}$	7	2	7	*	59
Progress	Total	68	53	46	41	19	29	22	14	11	8	311

* A whorl of dead branches.

NOTE.—Numbers surmounted by a dot indicate a decrease in egg numbers from the previous day, due to the activity of predators.

Light showers of rain which fell on the third and fourth nights after the pruning probably explain the rapid increase in the number of eggs laid. Sometimes, owing to the activity of predatory insects, the number of eggs observed on successive days was less than the stated figure, which is comprised of eggs actually seen and stains of the egg covers from which eggs had disappeared. On some occasions the egg counts on successive days show a decrease on individual stubs or individual whorls; on tree C this decrease applied to almost the whole tree on the fourth day.

Table 13.

Egg Counts Showing Distribution and Rate of Oviposition on Pruned Trees.

(March, 1938).

Day after Pruning.	Tree.	Whorl.									
		Top.	2nd.	3rd.	4th.	5th.	6th.	7th.	8th.	9th.	Totals.
2nd	A	5	0	0	0	*	*	*	*	*	5
	B	7	2	1	0	2	0	*	*	*	12
	C	1	0	0	0	0	0	*	*	*	1
	D	11	18	24	7	7	5	2	2	3	79
	E	4	2	1	1	1	1	0	*	*	10
Progress Total ..		28	22	26	8	10	6	2	2	3	107
3rd	A	5	0	0	0	*	*	*	*	*	5
	B	7	4	3	0	2	0	*	*	*	16
	C	1	0	0	0	0	0	*	*	*	1
	D	16	22	28	8	17	7	2	2	3	105
	E	6	2	2	1	1	1	0	*	*	13
Progress Total ..		35	28	33	9	20	8	2	2	3	140
4th	A	$\dot{1}$	0	0	0	*	*	*	*	*	$\dot{1}$
	B	7	5	$\dot{2}$	0	2	0	*	*	*	16
	C	1	0	0	0	0	0	*	*	*	1
	D	17	$\dot{19}$	$\dot{23}$	10	20	$\dot{5}$	4	4	4	106
	E	6	2	2	1	1	1	0	*	*	13
Progress Total ..		$\dot{32}$	$\dot{26}$	$\dot{27}$	11	23	$\dot{6}$	4	4	4	$\dot{137}$
6th	A	$\dot{1}$	0	0	2	*	*	*	*	*	3
	B	10	15	17	6	5	0	*	*	*	53
	C	7	3	1	7	1	1	*	*	*	20
	D	$\dot{14}$	19	28	$\dot{7}$	$\dot{18}$	7	6	$\dot{3}$	4	106
	E	6	2	2	2	4	1	2	*	*	19
Total ..		38	39	48	24	28	9	8	$\dot{3}$	4	201

* A whorl of dead branches.

Note.—Numbers surmounted by a dot indicate a decrease in egg numbers from the previous day, due to the activity of predators.

In the March test (Table 13) the trees carried from four to nine whorls of green stubs, the mean being 6·5, again with a mean of five stubs per whorl. By the second day a mean of 21·4 eggs per tree had been laid. This increased to 28·0 eggs per tree by the third day, but a decrease to 27·4 eggs per tree occurred on the fourth day. However, by the sixth day the increase was again evident, with a mean of 40·2 eggs per tree. Rain fell almost continuously throughout the test and the excessive moisture on the stubs may have had a restraining influence on adult activity in this case. The low egg count on the fourth day was made after a night of continuous, steady rain. Misty rain fell on the fifth and sixth day intervals, but an increase in egg numbers occurred during this period.

Continuous, steady rain saturated the surfaces of the cuts and many of the pruned stubs then had very few eggs laid on them. On tree D, the stubs, owing to the angle of the cut, held little free moisture and egg-laying exceeded the aggregate of the other four trees.

If the decreases recorded in Tables 12 and 13 are ignored and the previous totals are carried forward, the progressive total numbers of eggs laid on the five trees are as follows:—

	2nd day.	3rd day.	4th day.	6th day.
February ..	139	237	325	—
March	107	140	152	225

These figures may underestimate the amount of egg-laying for the stated intervals, as predatory insects could have devoured numerous eggs without traces of their attacks being shown.

During the course of the above observations, it was noticeable that the number of eggs about each whorl varied with its position on the tree. All the available data (Table 14) show that more eggs—28·2 per cent. of the total—

Table 14.

Egg Counts Showing Distribution of Eggs on Whorls of Pruned Trees.

—	Tree.	Green Whorls.										
		Top.	2nd.	3rd.	4th.	5th.	6th.	7th.	8th.	9th.	10th.	Totals.
Jan., 1938	P.76	24	11	12	19	9	4	10	11	2	4	106
	P.77	16	22	21	11	6	10	3	..	..	..	89
	P.78	23	35	27	15	12	16	10	1	..	..	149
	P.79	44	28	26	21	24	23	4	7	9	4	190
	P.80	76	14	11	7	14	5	4	2	..	..	133
January Totals		203	110	97	73	65	48	31	21	11	8	667
February and March Totals*		106	92	94	65	47	38	30	17	15	8	512
Other Monthly Observations		159	103	94	50	34	26	6	5	2	3	482
Totals		468	305	285	188	146	112	67	43	28	19	1,661
Percentage ..		28·2	18·4	17·1	11·3	8·8	6·7	4·0	2·6	1·7	1·1	

*See Tables 12 and 13.

were laid on the top whorl than on any other whorl of stubs, while almost two-thirds of the total was laid on the upper three whorls (Figure 3). The explanation of the data no doubt lies in the fact that the pruned branches of the upper whorls are the largest and most vigorous of those removed and, therefore, the stubs of these exercise a greater attraction to females than those lower on the trunk.

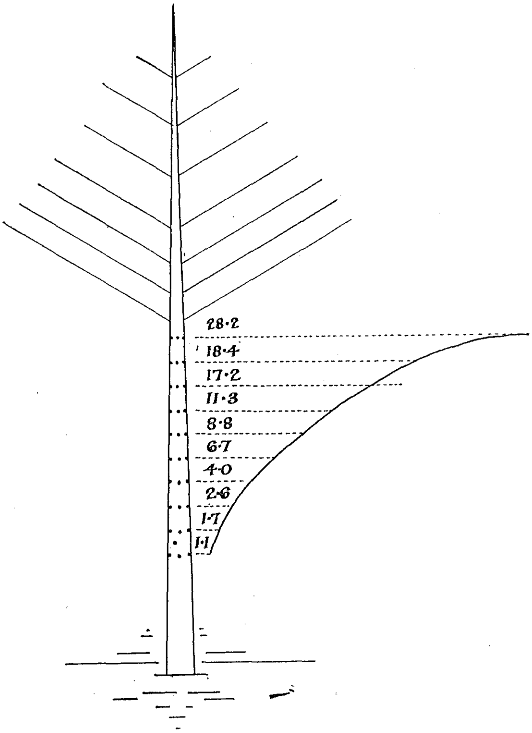

Figure 3.

Diagrammatic representation of a hoop pine tree, showing percentage of egg distribution on the stubs of each whorl. Note the preference for the upper whorls.

The Influence of Food on Oviposition.

Experiments on the influence of food on adult longevity, which extended for 108 days, also yielded some data on the influence of food on oviposition. Mated females kept in tubes without food lived for a mean period of 17·9 days and laid a mean of only 2·6 eggs. These eggs were laid mostly within a few days from the commencement of the experiment and could represent a latent effect of the previous normal diet. Females supplied with fresh hoop pine foliage laid eggs more freely than those kept without food. They survived for a mean period of 64·2 days and laid on an average 8·3 eggs each, the greatest number for an individual being 20. Oviposition by laboratory adults provided with fresh bark as food was normal, each female averaging about three eggs per day.

Oviposition in the Absence of Males.

On a number of occasions, females continued to oviposit at the normal rate for some time after the death of the associated male. One female laid 103 eggs in four months and another 263 eggs in five months after the death of the respective males and laying had even then not ceased. All the eggs were fertile in both cases. The presence of a receptaculum seminis in the reproductive organs of the female would account for the laying of fertile eggs for some time after the death of the male.

Several laboratory-bred females were isolated after emergence. Some laid a few eggs, but these failed to hatch and showed no sign of embryonic development when dissected. Parthenogenesis, therefore, does not appear to be a characteristic of the pine bark weevil, though it has been recorded for a few other species of the same family. Fidler (1936), working on four species of *Otiorrhynchus,* says that ''all of them are probably always parthenogenetic, the presence of males apparently never having been recorded.'' Palm (1935), working on *Brachyrhinus ligustici* L., also of the sub-family Otiorrhynchinae, never observed males: the dissection of more than 1,000 field-collected adults showed that all were females.

THE INFLUENCE OF TEMPERATURE AND HUMIDITY ON DEVELOPMENT AND HABITS.

The environment of any insect plays an important role in determining its behaviour. The principal meteorological factors of the environment are temperature and humidity, and either or both can be adequately controlled in the laboratory, where detailed studies of the independent or combined action of the major environmental factors on each developmental stage are alone possible. Most laboratory investigations on the influence of temperature and humidity have been carried out over a wide range of constant temperatures and humidities. Such conditions differ from those existing in the field, but laboratory studies can assist greatly in the interpretation of field data.

Methods of expressing the influence of temperature on insect development in graphical form are not standardized, mainly because of lack of agreement on the manner of treating the reduced rate of development which occurs above a temperature which has been defined by Davidson (1942) as the ''peak temperature.'' Janisch (1932) devised a mathematical formula which, when applied to the data, gives an asymmetrical curve, whereas Davidson used a bisymmetrical logistic curve. No mathematical formula has been used in constructing the curves representing the time-temperature and temperature-developmental rate relationships of the data secured in this investigation: smooth curves have been fitted to the relevant data, and the reciprocal curves are therefore sigmoid and recurved at the upper end.

The Influence of Temperature.

Influence on Oviposition.

Adults of the pine bark weevil are numerous in the plantation throughout the year and a knowledge of seasonal variations in the amount of oviposition should, therefore, be useful in the advance planning of plantation operations. Under plantation conditions, oviposition appears to be influenced by rainfall rather than by temperature. However, even though the seasonal extremes of laboratory temperatures are not widely divergent, seasonal variations in oviposition show an evident trend inverse to temperature. This is illustrated by the monthly egg-laying records of adults kept under observation for the 12 months ending July, 1937 (Table 15).

Table 15.

EGG-LAYING IN THE LABORATORY.

——	1936.					1937.						
	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.
Mean Number of eggs per female	9·0	11·3	2·6	1·5	1·2	0·0	1·7	8·4	15·1	27·2	33·8	12·3
Mean Monthly Temp. Deg. C.	20·5	22·1	24·9	26·0	27·2	27·2	26·0	25·1	23·2	21 0	18·0	17·2

In August, 1936, the average oviposition per month was comparatively low at a mean temperature of 20·5 deg. C. A slight rise in oviposition in September was followed by a progressive decline as temperatures gradually increased. In January, 1937, with a mean of 27·2 deg. C., no eggs whatever were laid. However, the subsequent decline in temperature was accompanied by a resumption of egg-laying, which gradually increased to a mean maximum of 33.8 eggs per female per month in the cold month of June, when the mean temperature was 18·0 deg. C. These results therefore indicated that, under laboratory conditions, oviposition was negligible above 25.0 deg. C.

A second experiment provided confirmatory data. Pairs of adults known to be laying eggs at the normal rate were distributed through a multiple-temperature incubator for a period of 132 days at temperatures between 4·6 deg. C. and 42·9 deg. C. Eggs were laid at all temperatures between 4·6 deg. C. and 32·0 deg. C. It was not expected that a tropical and sub-tropical insect should oviposit at the low temperature at 4·6 deg. C. With higher temperatures there was a fluctuating upward trend in oviposition, until at 21·8 deg. C. the greatest mean number of eggs per female—374·5—was laid. Slightly higher temperatures were accompanied by a decline in oviposition, but a second peak occurred at 26·0 deg. C., with a mean of 327·5 eggs per female; still higher temperatures produced a very rapid decline in egg production. Above 31·0 deg. C. beetles did not survive the duration of the test, but a few eggs were laid at temperatures as high as 33·3 deg. C. before the females died.

The various temperatures did not alter the choice of oviposition site and, as under ordinary laboratory conditions, eggs were laid chiefly in the vicinity of the bark.

In the laboratory, the range of temperature over which oviposition occurred was very wide, but most eggs were laid between 18·0 deg. C. and 28·0 deg. C., which are respectively 2·0 deg. C. below and 8·0 deg. C. above the mean annual plantation temperature. Variations in the mean monthly plantation temperatures from this annual mean during 1936-38 did not exceed 7·0 deg. C. and, therefore, late spring, summer, and autumn temperatures are uniformly within the range favourable to oviposition. The comparatively low number of eggs recorded in the plantation during the winter and early spring months might have been due partly to low temperatures, but since a moderate number of eggs was laid in the laboratory at temperatures below the lowest plantation monthly mean it is reasonable to suppose that the absence of moisture in the winter and early spring months played a much more important part in restricting oviposition.

Influence on Incubation and Viability of the Egg.

Five pine bark weevil eggs were placed in each of a number of tubes, together with fragments of the bark on which they were laid, and the tubes were spaced throughout the multiple-temperature incubator, the compartment temperatures ranging from a mean of 10·2 deg. C. to a mean of 42·5 deg. C. Hatching took place at all temperatures between 10·2 deg. C. and 32·2 deg. C. The most rapid development occurred at temperatures near 27·0 deg. C., at which some eggs hatched in five days, means of 5·2 and 5·4 days being obtained. Both above and below this temperature the incubation period increased, the maximum being 41·5 days at 10·2 deg. C.

Incubation periods plotted against temperatures at which the eggs were held give a more or less smooth curve. The sigmoid velocity curve obtained by plotting the reciprocals of time against temperature would indicate a threshold of development for the egg stage at about 4·0 deg. C. (Figure 4).

All eggs held at temperatures near 22·0 deg. C. and near 27·0 deg. C. hatched and a hatching of 60 per cent. was obtained at a mean temperature as low as 10·2 deg. C. The range of temperature within which embryonic development can take place is, therefore, very wide.

Influence on Larval Survival.

A breeding technique in which larvae were established between pieces of bark was used to determine the influence of temperature on larval establishment between 10·2 deg. C. and 42·0 deg. C. Larval mortality was low at all temperatures from 10·2 deg. C. to 27·1 deg. C. At 36·2 deg. C. the larvae lived for a few days and slightly eroded the inner, moist surface of the bark, but there was no attempt to burrow into it. Establishment of newly-emerged pine bark weevil larvae is, therefore, possible over a very wide range of temperature.

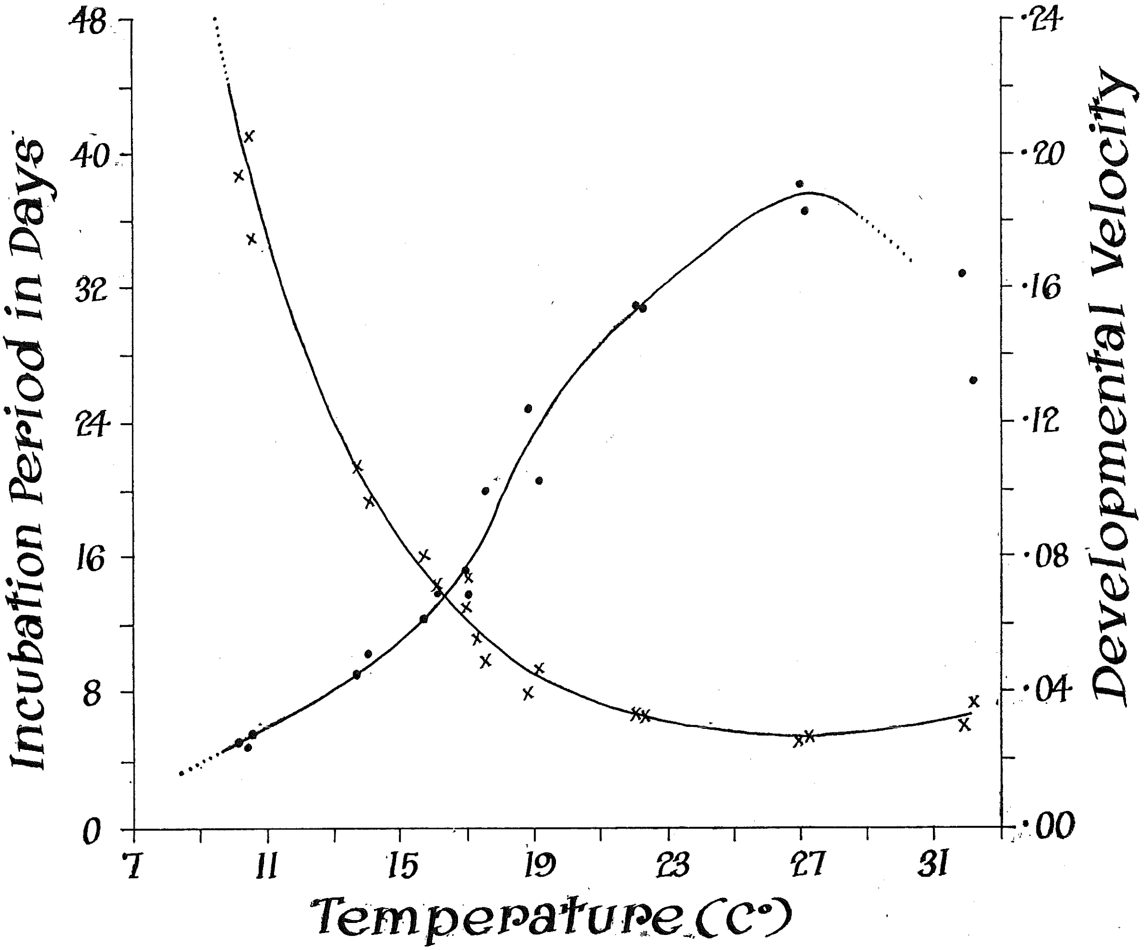

Figure 4.

Showing the influence of temperature on the incubation period.

× Recorded incubation periods.

• Reciprocals of incubation periods.

Influence on the Duration of the Larval Period.

Pine bark weevil larvae feed on living plant tissue and the influence of temperature on the duration of the larval period could not be experimentally separated from that of other factors, e.g., moisture content and decay of the tissues. However, by establishing newly-emerged larvae in hoop pine blocks maintained in as fresh a condition as possible over a range of temperatures an idea of the influence of temperature was obtained.

Several difficulties were encountered in the experiment. At high temperatures the blocks rapidly dried out, while at both high and moderately low temperatures decay soon developed and spread through the bark. Wrapping the blocks in grease-proof paper had little beneficial effect at high temperatures,

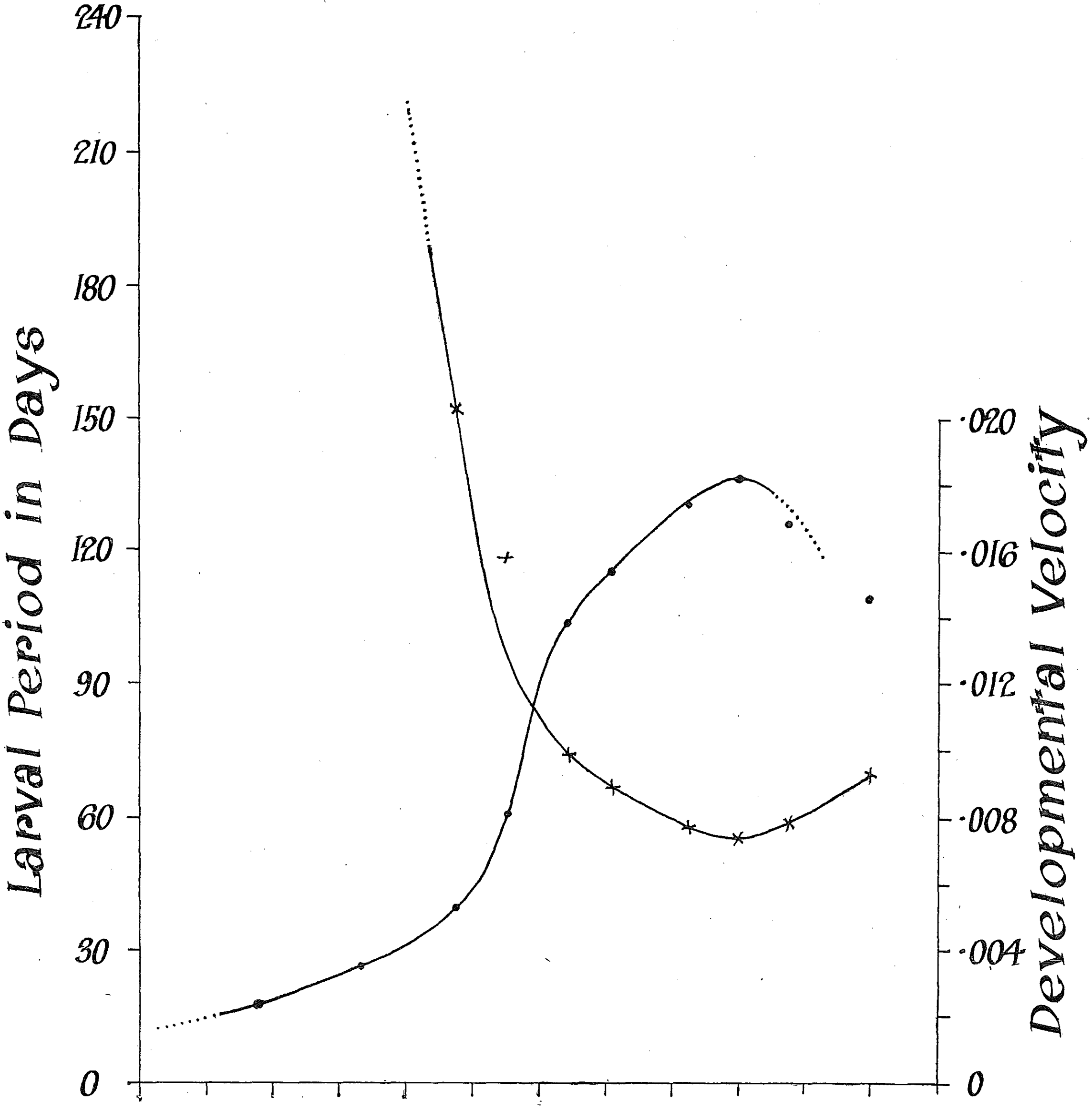

Figure 5.

Showing influence of temperature on the duration of the larval period.

× Recorded larval periods.

• Reciprocals of larval periods.

and it was usually necessary to transfer the larvae to fresh blocks at short intervals. Larval mortality during transfer from block to block in this experiment was high and development to the pupal stage was obtained only at temperatures ranging from 19·9 deg. C. to 29·3 deg. C. It appears that temperature exerts a marked influence on the length of the larval period. The maximum rate of development probably occurs between 24·0 deg. C. and 25·0 deg. C. Both higher and lower temperatures increased the life of the larvae, which at 19·9 deg. C., the lowest temperature recorded, lasted 99·0 days.

In a further experiment (Figure 5), newly hatched grubs were placed between two pieces of fresh bark bound together by a rubber band, and enclosed in two-ounce, screw-cap, glass jars which were then placed in the various compartments of the multiple-temperature incubator. Food supplies could thus be changed without any undue disturbance of the insects. The presence of moist bark in the small jars should have maintained the humidity at a relatively high level. At 35·0 deg. C. larvae established themselves within the bark, but failed to moult to the second stage. At 30·6 deg. C. the grubs died in the last instar and a mean period of 80·5 days was required for development to that stage. At temperatures ranging from 10·5 deg. C. to 28·8 deg. C. larval development was completed in periods varying from a minimum of 54·5 days to a maximum of 395.0 days. Development was most rapid at 25·0 deg. C. The sigmoid velocity curve indicates a threshold of larval development at about 0·0 deg. C.

Influence on the Pupal Period.

At relative humidities ranging from 90 to 94 per cent., pupal development was completed at all the temperatures used that lay between 14·8 deg. C. and 33·1 deg. C. The maximum developmental rate occurred at 30·2 deg. C., which is a higher temperature than that recorded for either the egg or the larva (27·0 deg. C. and 25·0 deg. C. respectively). The sigmoid velocity curve indicates a threshold of development at about 4·0 deg. C., similar to that for the egg.

Influence on Adult Longevity.

Laboratory work showed that adults may live for long periods and that little could be expected from a study of the influence of temperature on longevity in short-period tests, except perhaps at high or low temperatures. Field-collected beetles were, however, maintained in 4 inch by 1 inch flat-bottomed glass tubes at various temperatures and provided regularly with fresh food. At the higher temperatures desiccation of the bark was rapid and food had to be renewed almost daily, while at the lower temperatures the bark remained fresh for some time.

Little significance can be attached to the deaths of beetles at temperatures below 30·0 deg. C.; the insects were few in number and may have been aged. No beetles survived the test period of 132 days at temperatures above 31·0 deg. C. At 31·7 deg. C., death occurred in the comparatively brief period of 20 days.

The longevity then declined with rises in the temperature and at 42·9 deg. C. all beetles were dead on the day following exposure. At a temperature of 3·0 deg. C., the beetles became dormant, but resumed normal activity when returned to higher temperatures. At a temperature of —1·0 deg. C., beetles became encased in ice, but they resumed their normal activity when returned to laboratory conditions after five days' exposure to this temperature.

The Combined Influence of Temperature and Food.

Influence on Oviposition.

Tests conducted in the incubator over a period of 132 days with two pairs of field-collected beetles in each temperature compartment (Figure 6) showed that the kind of food consumed by the beetles has a marked effect on oviposition.

(*a*) No food (dry conditions):—When beetles were kept without food at temperatures between 4·6 deg. C. and 42·3 deg. C., eggs were laid at all temperatures below 27·7 deg. C. The maximum number of eggs laid by any female in this test, however, was only five and, therefore, the variation in numbers laid at the different temperatures is not important. All these eggs were laid within a few days of the initiation of the test, prior to which the insects were held under normal conditions.

(*b*) No food (moist conditions):—In this experiment the beetles lacked food, but a piece of wet cotton wool was enclosed in the container. Some beetles appeared to extract moisture from the wool, especially at the higher temperatures. Egg-laying (maximum number, 19) was greater than that of beetles kept without food under dry conditions, and took place over a wider range of temperatures. Eggs were laid at practically all temperatures from 4·6 deg. C. to 36·6 deg. C. The mean number of eggs laid at any temperature was again small and the eggs were deposited soon after the initiation of the experiment.

(*c*) Fresh foliage as food:—Adults were supplied with fresh foliage as food during the term of the experiment. The number of eggs laid was much greater than that by adults deprived of food. Oviposition occurred at temperatures ranging from 4·6 deg. C. to 36·6 deg. C., with the greatest number of eggs for an individual (48) at 19·7 deg. C. The deposition of eggs was not confined to a brief period following the initiation of the test but extended over several months and in some cases eggs were still being laid when the test concluded after 132 days.

(*d*) Fresh bark as food:—A preliminary experiment on the influence of temperature on oviposition, with fresh bark as food, indicated that the most favourable temperature range for oviposition lies between 19·5 deg. C. and 25·5 deg. C. In a second experiment,

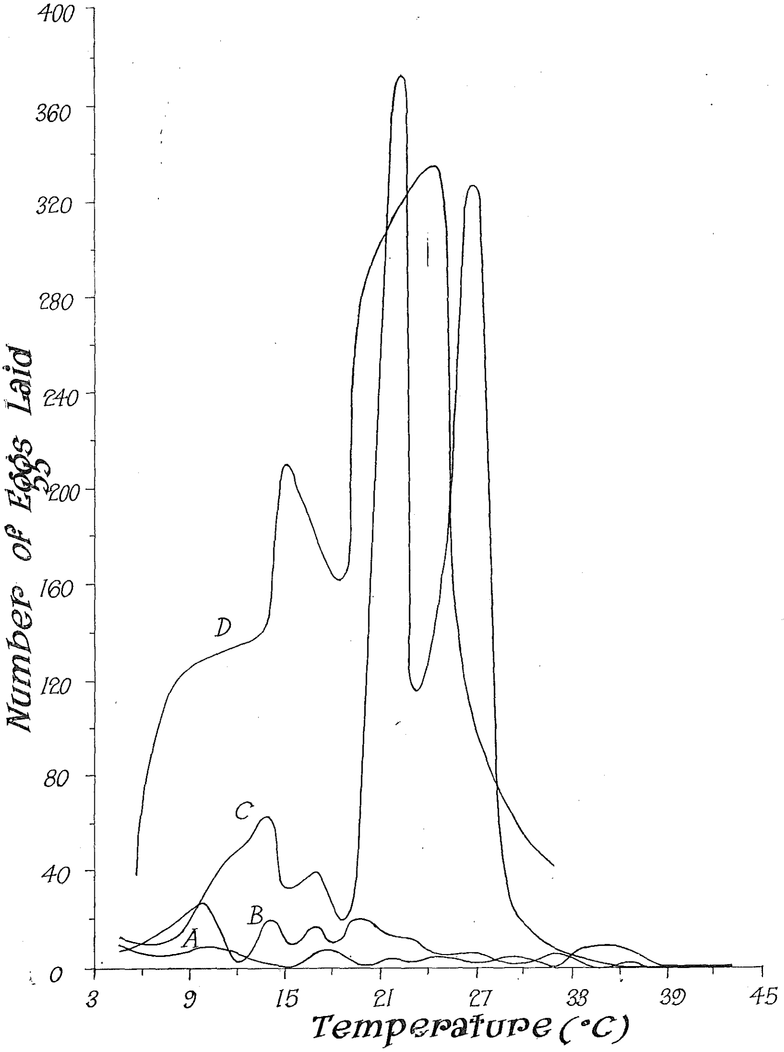

Figure 6.

Showing the influence of food and temperature on oviposition.

Line A.—Mean number of eggs laid by two mated pairs of adults in 132 days without bark or foliage.

Line B.—Mean number of eggs laid by two mated pair of adults in 132 days with foliage only.

Line C.—Mean number of eggs laid by two mated pairs of adults in 132 days with bark only.

Line D.—Total number of eggs laid by six mated pairs of adults in 18 days with bark only.

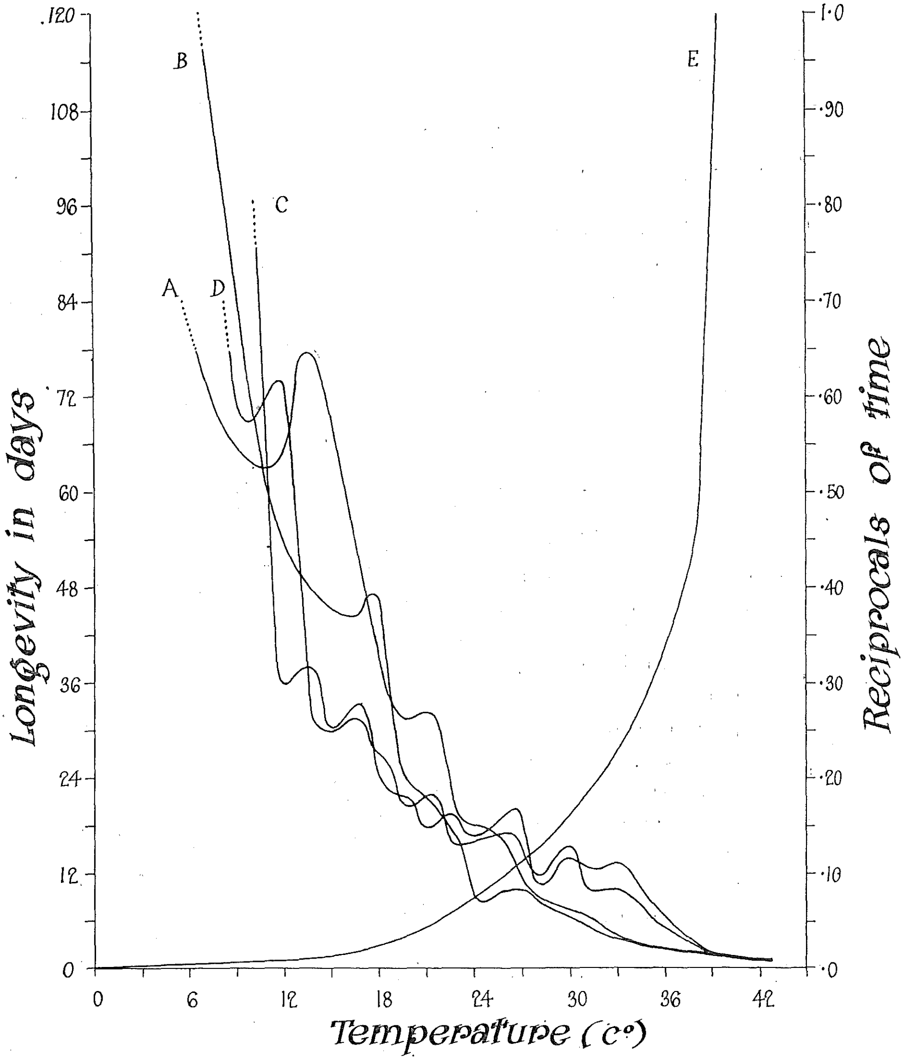

Figure 7.

Showing influence of food and temperature on adult longevity.

Line A.—Longevity of adult females without food and under dry conditions.

Line B.—Longevity of adult males without food and under dry conditions.

Line C.—Longevity of adult females without food and under moist conditions.

Line D.—Longevity of adult males without food and under moist conditions.

Line E.—Reciprocals of time plotted against temperature.

E

eggs were laid at all temperatures ranging from 4·6 deg. C. to 33·3 deg. C., the smallest numbers being at these extremes. From the extremely low temperature the rate of egg-laying gradually increased with increases in temperature until the maximum mean of 374·5 was reached at 21·8 deg. C. A secondary peak of 327·5 eggs appeared at 26·0 deg. C.

The oviposition records of adults kept with and without food at various controlled temperatures show that food exercises an important influence on oviposition. When fresh foliage was supplied the rate of egg-laying was almost negligible compared with that obtained when fresh bark was fed to the beetles. Conversely, when the food requirements of pine bark weevils are satisfied, the influence of temperature becomes noticeable. Normal egg-laying then occurs at temperatures between 20 deg. C. and 28 deg. C. Outside this range, the rate of egg-laying rapidly diminishes. Summer plantation temperatures correspond closely to the normal egg-laying optimum in the laboratory and a reproductive peak in the warmer months can thus be inferred from the data.

Influence on Adult Longevity.

The influence of temperature on the longevity of pine bark weevils (Figures 7 and 8) was investigated under the following conditions:—

(*a*) Without food (dry conditions):—All beetles, except two males held at a mean temperature of 4·5 deg. C., died within a test period of 132 days. The survivors were held still further under the same conditions and succumbed in 140 and 151 days, respectively. At temperatures below 7·5 deg. C., the males appreciably outlived the females, but at higher temperatures the reverse was usual. With each increase in temperature the longevity of both sexes declined, until at 39·5 deg. C. all were dead within 24 hours.

(*b*) Without food (moist conditions):—All beetles died during the test period except a few held at temperatures below 6·5 deg. C. With each increase in temperature the length of life became less, until at 39·3 deg. C. the insects died within 24 hours. Under like conditions, there was no outstanding difference between the longevity of females and that of males.

(*c*) Fresh foliage as food:—Most of the beetles held at temperatures below 14·0 deg. C. outlived the test period of 132 days. Above 14·0 deg. C. the length of adult life decreased, until at 39·4 deg. C. the beetles failed to survive for more than one day. Females in this test generally outlived males. Feeding occurred at all temperatures below 37·0 deg. C., but to a reduced extent outside the limits of 12·0 deg. C. and 33·0 deg. C.

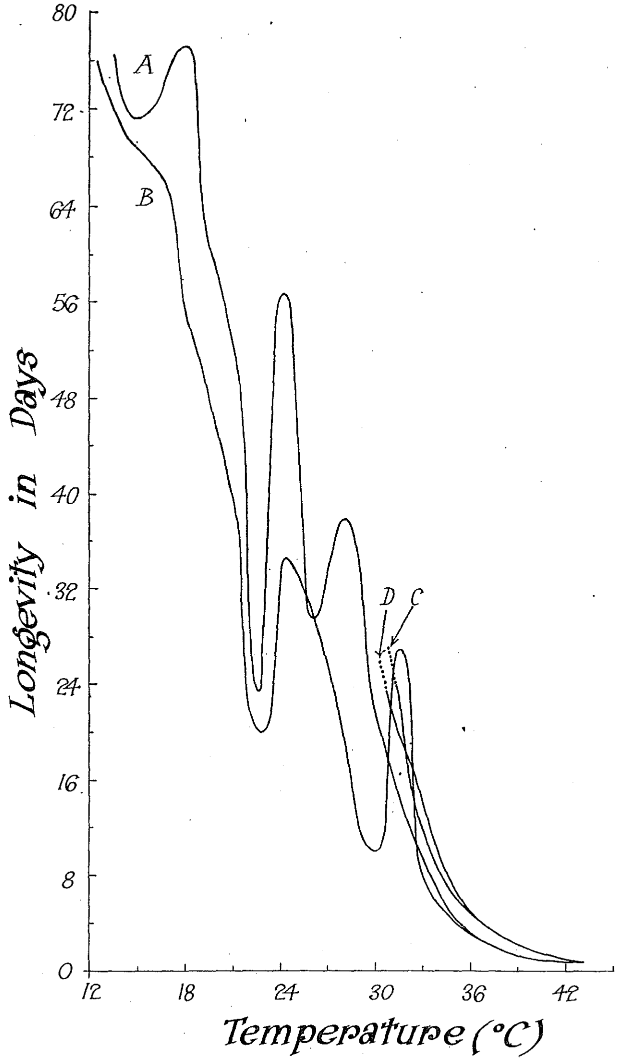

Figure 8.

Showing influence of food and temperature on adult longevity.

Line A.—Longevity of adult females provided with foliage only.

Line B.—Longevity of adult males provided with foliage only.

Line C.—Longevity of adult females provided with fresh bark only.

Line D.—Longevity of adult males provided with fresh bark only.

(*d*) Fresh bark as food:—All beetles survived temperatures below 30·0 deg. C., but at higher levels death was comparatively rapid. Feeding occurred at all temperatures below 37·0 deg. C., and appeared to be normal within the range from 12·0 deg. C. to 33·0 deg. C., outside which it declined. At the lowest temperature used—4·6 deg. C.—the beetles were sluggish and fed only to a very slight extent.

Without food, beetles held under dry conditions died fairly quickly. At temperatures below 11·0 deg. C. and above 23·0 deg. C., beetles kept without food under moist conditions lived longer than those under dry conditions. Between these temperatures the reverse was the case. Adults supplied with fresh foliage lived longer than those kept in moist conditions without food, but even so these beetles lived for only a short time and, therefore, fresh foliage must be considered a poor substitute for fresh bark as food. Fresh bark which permits beetles to feed on the cortex and phloem appears to be the normal food, and with it adults live for a long time under ordinary laboratory conditions.

For adult longevity, the reciprocals of time when plotted against temperature give a series of points which best fit a gradually declining smooth curve, which indicates a threshold of activity approximating 0·0 deg. C.

The time-temperature curve for the development of the immature stages of the pine bark weevil indicates a temperature point at which physiological functions proceed at the maximum rate. Higher temperatures retard development until the critical point at which death occurs is reached. With adults, however, temperatures above the optimum for reproduction diminish the life of the insect and time-temperature curves for longevity do not, therefore, show a lower limit.

The Combined Influence of Temperature and Humidity on Development.

A chart reproduced by Tsai (1935) after Janisch, showing humidities obtainable at different temperatures with saturated solutions of various inorganic salts, proved useful in studying the combined influence of temperature and humidity on the pine bark weevil, but for completely dehydrated atmospheres, sulphuric acid was used. The various solutions were prepared in 4 inch x 1 inch flat-bottomed glass tubes, within which a stable humidity must have soon been reached. The insect stages under test were placed in two-dram vials, which were suspended in the larger tubes and the latter then tightly closed by greased corks. Observations on development could thus be made without any interference with the humidity inside each tube.

Influence on Incubation.

Five freshly laid eggs were used with each combination of temperature and humidity. Within saturated atmospheres, the eggs hatched at all temperatures between 9·5 deg. C. and 28·3 deg. C. Development was most rapid at 26·4 deg., at which temperature the mean incubation period was 4·8 days. This was the minimum mean incubation period recorded throughout the whole

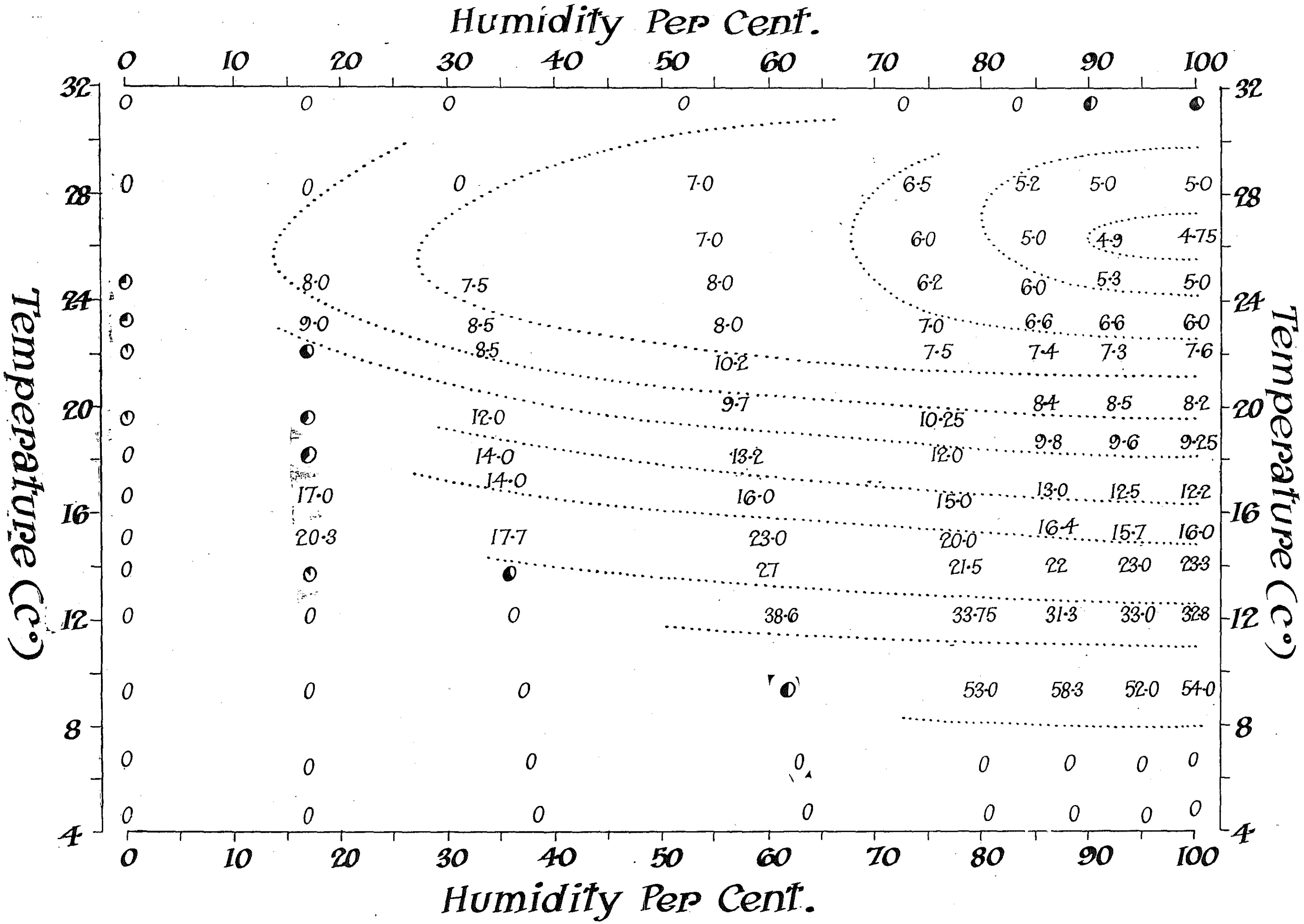

Figure 9.

Showing influence of temperature and humidity on incubation.

Figures within ordinates represent incubation periods at each point in days. Plain ellipses indicate no development.
Partially shaded ellipses indicate partial development. . . . . Lines grouping similar periods at various temperatures and humidities.

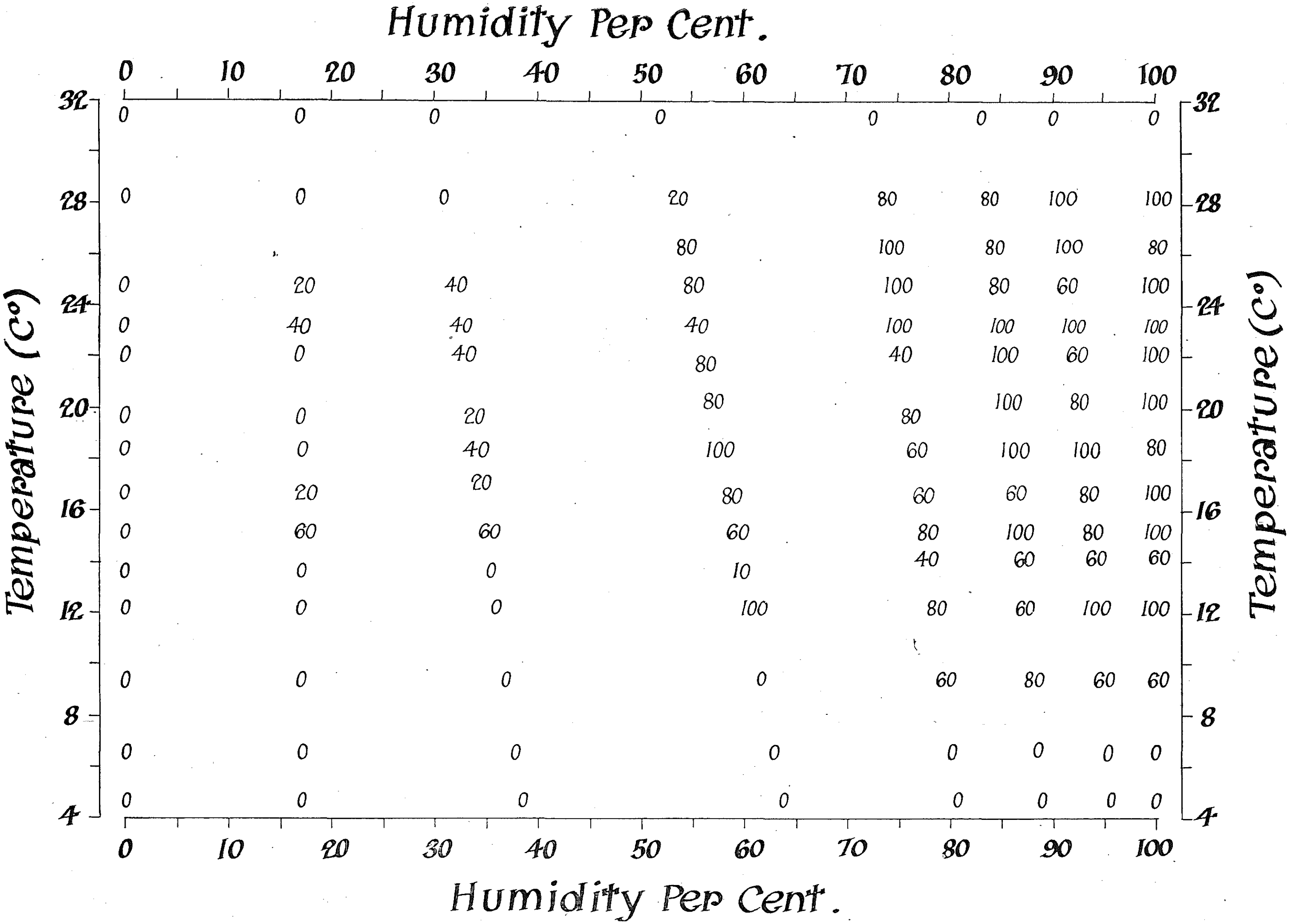

Figure 10.

Showing influence of temperature and humidity on egg viability. Figures within ordinates represent percentage hatching at each point.

of the investigations. The longest mean incubation period at 100 per cent. humidity was the 54-day period recorded at 9·5 deg. C. At humidities between 100 per cent. and the 58 per cent. group*, each drop in the humidity at any given temperature induced a corresponding lengthening of the incubation period, but the range of temperatures at which hatching occurred remained the same. At humidities of the 58 per cent. group and lower the incubation period lengthened still further and at the same time the temperature range within which hatching was possible narrowed considerably. Some hatching occurred at a humidity of 17 per cent., but none at lower levels.

The experimental data is illustrated in Figure 9, where freehand lines grouping similar periods at various temperatures and humidities are inserted. These show that the minimum incubation period occurs at humidities between 90 per cent. and 100 per cent. in a temperature range from 25·0 deg. C. to 27·0 deg. C. Regression from these conditions is accompanied by a lengthening of the incubation period. From this data it appears that the threshold of development for the egg lies at a temperature of approximately 7·5 deg. C.

Influence on Viability.

Egg viability under normal laboratory conditions was usually high and some indication of the influence of temperature and humidity on viability can be deduced from the previous experiment. The summarized data (Figure 10) show that humidity has a marked influence on viability. At the higher humidities, hatching took place in the range from 9·5 deg. C. to 28·3 deg. C. However, at humidities of the 58 per cent. group and lower, the temperature range in which embryonic development was completed became very limited.

In the two-year period covering the investigations, the mean monthly relative humidity at the Mary Valley Forest Station was never below 50 per cent. The mean monthly plantation temperature is about 20·0 deg. C. Plantation temperatures and humidities therefore vary little from the optimum requirements of the egg and development should be possible during the whole year.

Influence on Newly Emerged Larvae without Food.

Humidity exercises an appreciable influence on the life of newly emerged larvae held without food. This point is confirmed by observations on larvae hatching from eggs used in incubation studies. The larvae emerging under each set of temperature and humidity conditions were held without food until death occurred. The maximum survival period of 6 days was recorded at 14·0 deg. C. in a saturated atmosphere. At all temperatures the larvae lived longer at high than at low humidities (Figure 11).

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* Group includes the humidity range produced by any single salt solution at various temperatures; e.g. 58 per cent. group—58 per cent. is the mean humidity within the range of temperatures used.

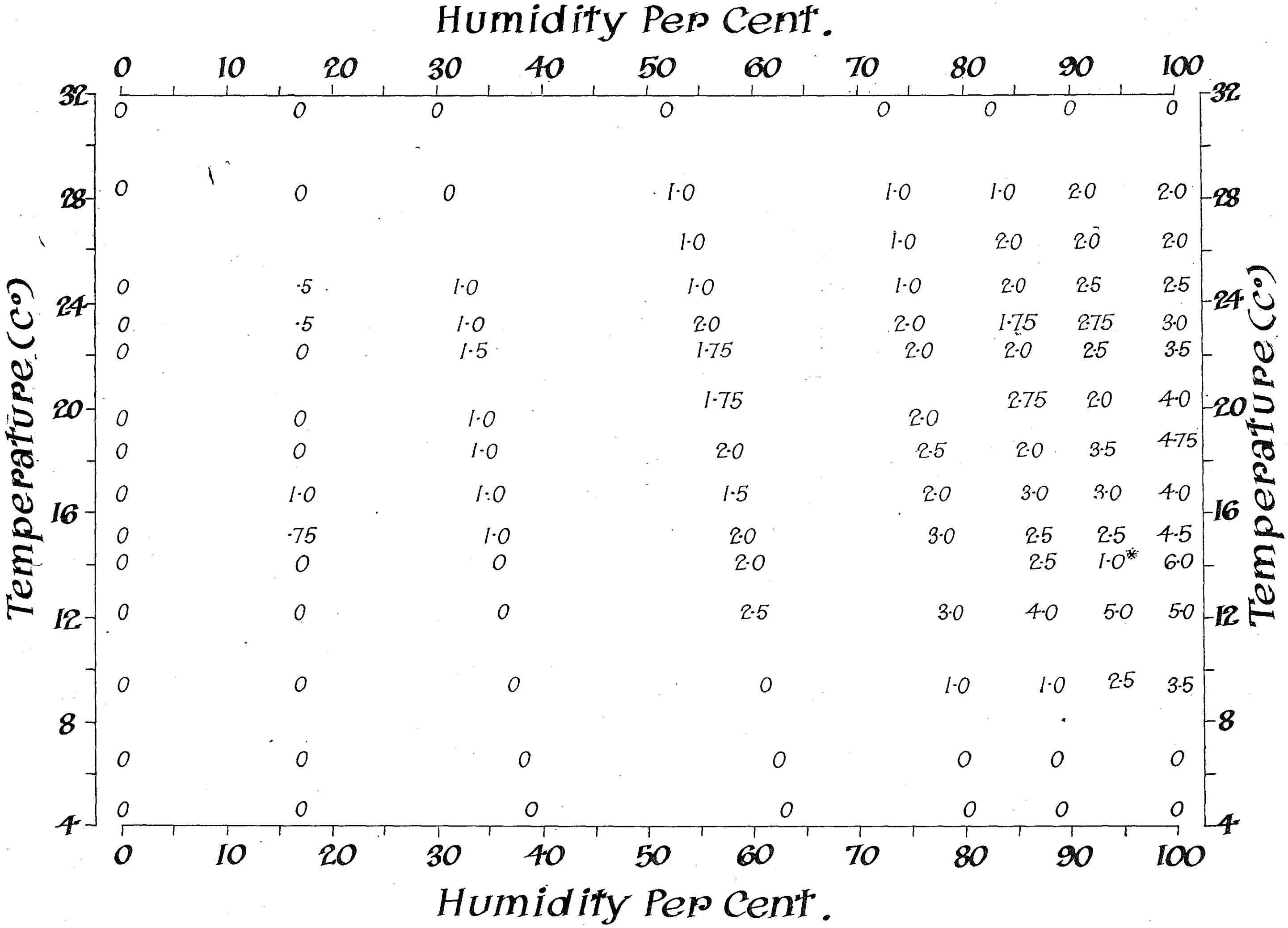

Figure 11.

Showing influence of temperature and humidity on the survival of newly emerged larvae in the absence of food. Figures within ordinates represent survival periods at each point in days.

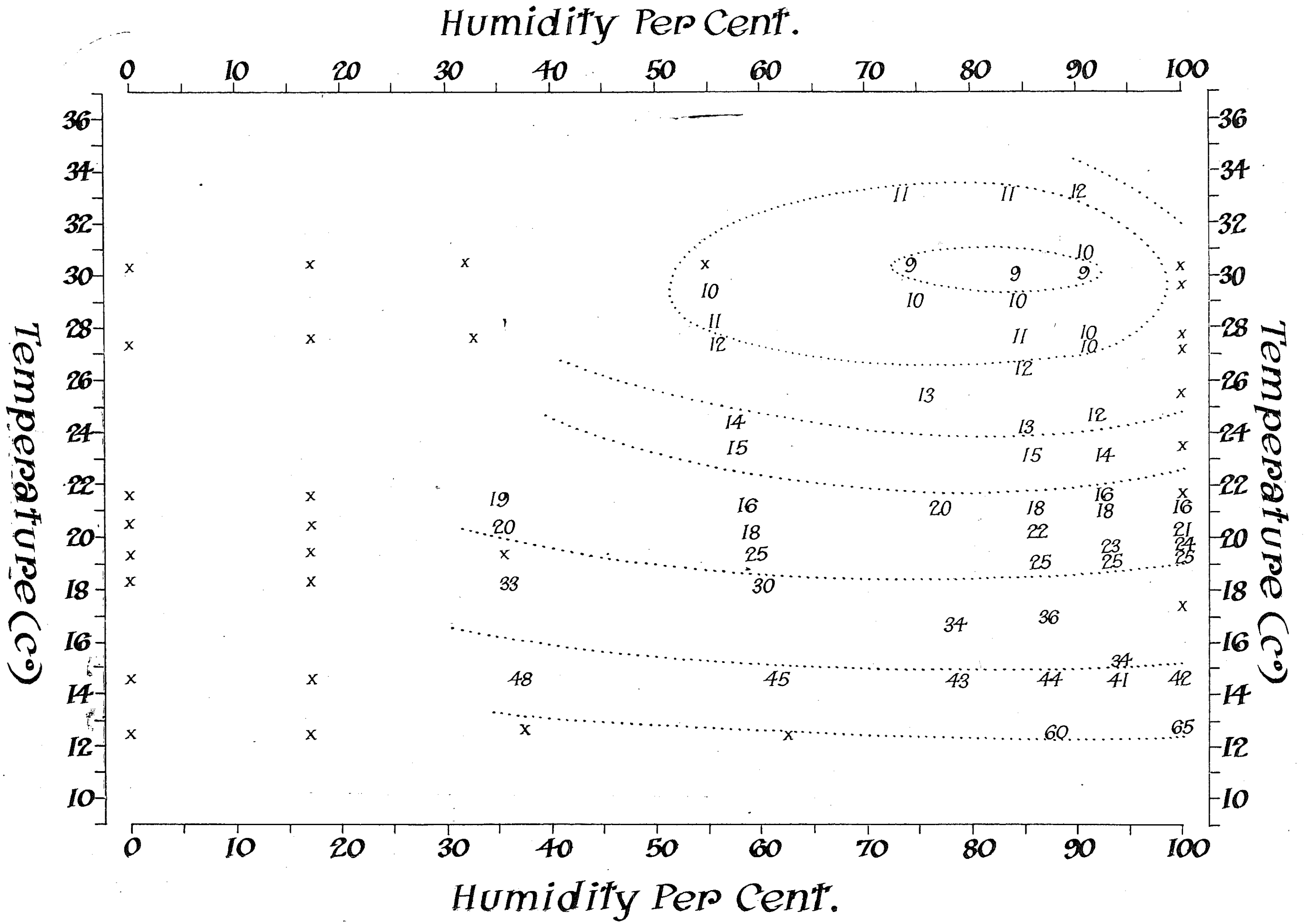

Figure 12.

Showing influence of temperature and humidity on the length of the pupal period.

Figures within the ordinates represent periods at each point in days. × Pupae failed to complete development.

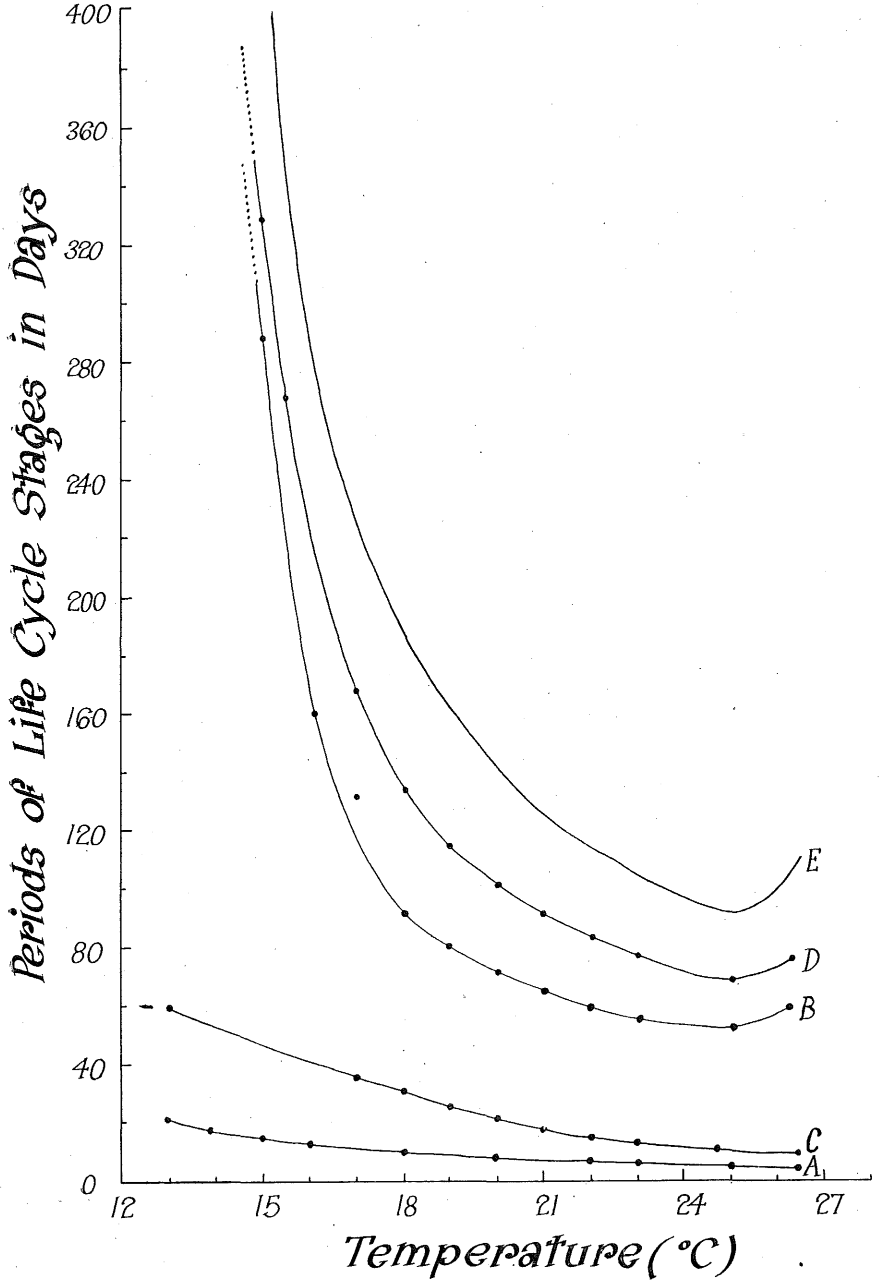

Figure 13.

Showing influence of temperature on the rate of development.

Line A.—Incubation periods.
Line B.—Larval periods.
Line C.—Pupal periods.
Line D.—Total of developmental periods.
Line E.—Estimated total life cycle—oviposition to oviposition.

Newly emerged larvae, if immediately placed in a very moist atmosphere, can be kept alive without food for a day and then established in hoop pine bark in the laboratory. However, if a longer period elapses between emergence and collection, the larvae can seldom be established and from the experimental work it was found that larvae must be established in the bark within one-third of the period for which they could live without food under each set of humidity-temperature conditions. It would thus appear that in the plantation, except in very moist weather, the larvae must establish themselves on pruned trees within a comparatively short time of hatching if they are to survive.

Influence on the Larval Period.

In the plantation, pine bark weevil larvae feed internally in living plant tissue, the moisture content of which is high, and atmospheric humidity can exert little influence on development. Temperature, however, has a very marked effect—if the rate of development is a sufficient criterion—for growth is rapid in summer and slow in winter. Under high humidity conditions in the laboratory, larval development was most rapid at 25·0 deg. C.

Influence on the Pupal Period.

The combined influence of temperature and humidity on pupal development was investigated by the technique previously used when studying the incubation period of the egg, but in this case one pupa was placed in each vial.

Pupal development was seldom completed in saturated atmospheres owing to the development of fungi; arid atmospheres were also fatal. The experimental data is summarized in Figure 12, and the freehand curves grouping similar periods at various temperatures and humidities indicate that moderately high to high humidities are most suitable for pupal development. The minimum pupal period of 9 days was recorded over the humidity range of 74 per cent. to 91 per cent. Within the humidity range from 74 per cent. to 95 per cent., the influence of moisture is more or less constant, but temperature exercises a marked influence; the optimum temperature was 30·3 deg. C. Humidities below 73 per cent. tend to inhibit pupal development.

DISCUSSION OF LIFE CYCLE AND SEASONAL HISTORY.

Life Cycle.

The rate of egg, larval and pupal development varies with both temperature and humidity. The shortest period required in the laboratory by each stage at various temperatures is indicated in Figure 13. The curve for the total developmental period of these three stages indicates a minimum of 69 days at 25·0 deg. C. By adding proportionate values for the periods elapsing between the emergence of the adult and the commencement of oviposition a further curve can be drawn which represents the complete life cycle from oviposition to oviposition. This indicates a minimum life cycle of approximately 92 days at 25·0 deg. C. The life cycle period gradually lengthens with decline in temperature until it extends over approximately one year at 15·5 deg. C.

At the mean summer plantation temperature of 24·0 deg. C., the life cycle as shown is about three months; at the mean winter temperature of about 17·5 deg. C., seven months; and at a temperature of 20·0 deg. C., which is the mean annual plantation temperature, five months. The laboratory data are in general agreement with field observations.

Seasonal History.

Adults of the pine bark weevil are present in the plantation throughout the year and at no time is there a cessation of egg-laying and development of immature stages. There are consequently no clearly defined seasonal generations.

Adult activity reached its highest peaks in the summer and autumn months, and declined to a minimum during winter. However, as the beetles live for a long time and continue egg-laying at comparatively low temperatures, the lack of activity in the plantation during winter must be due to some cause other than temperature. As rain is usually followed by increased activity, moisture appears to be an important stimulus to both egg-laying and adult attraction to pruned trees and thinnings. This conclusion agrees with that drawn from laboratory work, in which egg-laying and rate of development of the pine bark weevil was greatest in high humidities.

Temperature has, however, a direct influence on the development of immature stages and probably determines the number of generations possible in a year. Regular observations on the development of the pine bark weevil in the plantation suggest that during summer the complete life cycle covers about three months while in winter it is much longer—five to seven months. Two or three generations would, therefore, be completed in 12 months.

CONTROL.

Damage by forest insect pests is usually accentuated by outside influences which make the host more than normally susceptible to attacks. This is true of the pine bark weevil, which may be present in hoop pine plantations, even in large numbers, without any attacks being made on the trees until damage to stems occurs.

Control measures directed against the free living adult population in the plantation would be quite uneconomical and they were not attempted. The prevention or restriction of oviposition on the wounds might, however, be achieved by treating all cuts in living tissue in order to prevent egg-laying or to impede the entry of young larvae. Experiments were, therefore, initiated in 1936 to test the effect of chemical treatments on all wounds caused by pruning operations in the plantation. Details of these and of observations and experiments on various other aspects of control are given hereunder.

Chemical Control.

Pruning was about to commence on a large scale when the importance of the pine bark weevil was realized. In this operation, branches were to be removed to a height of 16 feet. Below four feet they were small and mostly dead, while at greater heights the green branches gradually increased in size to a maximum diameter of one-and-a-half inches, though the average of large branches was much less. In pruning away these branches the cuts were made with small handsaws as close to the bole as possible.

In order to provide some information on control as soon as possible, chemical means of preventing attacks were immediately investigated. The obvious procedure was to cover the branch stubs with materials which might either repel the beetles and thus prevent oviposition or prevent the young larvae from entering the stubs.

Materials in paste or fluid form were used and comprised the following:—

(*a*) Lime sulphur wash, consisting of 1 gallon of lime sulphur concentrate, 6 lb. of burnt lime, and 2 gallons of water.

(*b*) Bordeaux paste containing 1 lb. of copper sulphate, 2 lb. of burnt lime, and 1 gallon of water.

(*c*) Crude lanoline—a proprietary product in the form of a stiff grease.

(*d*) Cuprinol—a wood preservative, the active constituent of which has a copper base.

(*e*) Creosote.

(*f*) Creosote and kerosene in equal parts.

(*g*) Creosote and crude lanoline in the proportions 1 : 3.

(*h*) Bitumastic paint.

(*i*) Coal tar.

(*j*) Linseed oil.

The materials enumerated were used in one or other of four plantation experiments, each preparation being applied to the stubs immediately after pruning by spraying or brushing, the method depending on the consistency of the material. Pine bark weevil infestation was negligible both in the treated and the control trees in three of these experiments, a phenomenon due, as later life history studies showed, to the unsuitability of post-pruning climatic conditions for oviposition. In the fourth, however, oviposition occurred but few larvae were able to establish themselves in the stubs even on control trees. The materials used in this experiment were coal tar, creosote, bitumastic paint and linseed oil. Of these, coal tar and creosote prevented oviposition on the stubs.

The influence of the several treatments on gumming at the cut surfaces differed a great deal. Normally the small amount of exudation on the stubs is of no importance. Sometimes, however, it congeals into gum masses which adhere to the stub, and these if occluded by subsequent growth of the tree increase the volume of faulty timber in the bole. Only two of the treatments Bordeaux paste and Cuprinol, both of which contain a copper salt, increased the gum flow and thus the quantity of congealed gum on the stubs.

Normally the bark surrounding the woody core of a green stub lifts slightly and dies back for about a quarter-of-an-inch before occlusive growth begins. Products such as lanoline and bitumastic paint, which seal the stub, prevent this dying-back, but they stimulate sprout growth below the branch stubs to a greater extent than that on untreated trees. Coal tar and creosote very slightly accentuate the die-back of the stub bark, but occlusion is equally as rapid as on untreated trees.

Tree Banding.

When the investigations began it was presumed that the females crawled up the pruned trees to lay eggs on the stubs. The effectiveness of adhesive bands wrapped around the bases of the trees in preventing oviposition on the trees was, therefore, investigated. Adhesive rolls were wound round the trees to form a band four inches in width. These were sufficiently sticky to prevent beetles from crossing. A few of the beetles placed on them, though ultimately escaping, fell to the ground. When these adhesive bands were fastened to the bases of a number of freshly pruned trees, egg-laying still took place above them. Bands were then fitted both near the base and above the highest whorl of pruned branches on a further series of trees. Eggs were laid on the pruned stubs between the bands on most of the trees. The beetles had either managed to cross the adhesive bands or, as shown by other observations, had flown on to the tree trunks. Adhesive bands are therefore rejected as a possible method of preventing egg-laying on pruned trees.

Sylvicultural Practices.

Insecticidal control of insect pests in forest plantations has often a limited application and is almost invariably costly. This undoubtedly would be the case in hoop pine plantations in Queensland because the rugged nature of the country makes mechanical treatments impracticable and manual treatments would be difficult and slow. Indirect means of preventing attacks are sometimes available and often the successful management of forests depends on the practicability of growing the trees under conditions least favourable to to the insect pests.

As attacks by the pine bark weevil on plantation trees have been consistently associated with pruning, the only variable likely to have any appreciable bearing on the incidence of damage is the time of applying pruning as a routine practice in the plantation. It has been shown that adults are common throughout the year and, therefore, a knowledge of the conditions, particularly climatic conditions, determining activity (especially oviposition) is essential to advance planning of plantation operations.

The Influence of Climatic Conditions.

The principal climatic conditions governing insect activity are temperature and moisture. In the laboratory it was shown that oviposition was high between 18 deg. C. and 28 deg. C., but greatly decreased below 18 deg. C. Except in winter, plantation temperatures favour high oviposition. Plantation observations show that adult activity and the rate of egg-laying were low from May to October, which includes winter, and during which weather conditions were dry. Peaks in recorded adult population and egg-laying always followed wet weather, which normally occurs during the summer months and sometimes in the spring and autumn.

The greatest developmental rate during incubation occurred at 26 deg. C., in a saturated atmosphere, while at other temperatures the rate of development was consistently rapid in high humidities. The greatest viability occurred in saturated atmospheres and the same conditions favoured the survival of young larvae without food. Consequently the high temperatures and wet conditions in the plantation over the summer months would favour incubation, viability and larval survival, while the dry winter conditions would act unfavourably. The significance of these facts is increased by the small amount of oviposition in the winter and the shorter period during which the larvae are able to seek out sites for establishment.

The information obtained leaves little doubt that pruning operations should be carried out during the dry, cold, winter months. Soon after this impression was gained during the investigations, a large-scale pruning experiment was carried out during the winter and no noticeable attacks were recorded. Subsequently prunings have been conducted during the winter, and attacks have either not occurred or have been negligible. It is, nevertheless, desirable that pruning operations should cease for a week or so should moderate or heavy rain fall, even in midwinter.

Method of Pruning.

The attacks by pine bark weevil first experienced in the plantation followed pruning trials which had as their object the determination of the degree of care necessary in pruning. In these trials there was much bark injury as well as many jagged stubs in some of the treatments. Routine pruning, when applied, was, however, conducted with care. By means of small handsaws the branches were cut close to the bole with the least possible injury to the bark collar surrounding the stubs. However, the branches frequently snapped off before the cut was completed and left a jagged surface on the lower half of the stub. By exercising care and with tools in the best condition, it is possible to complete the saw cut before the branch breaks away and a clean and even surface then results. Oviposition and larval penetration are much more common on jagged than on smooth surface cuts except in wet weather.

Following pruning, the bark on the stubs dies back for one-quarter-of-an-inch or more and at the same time lifts slightly from the sapwood. On carefully pruned trees, lifting of the bark can normally occur only on the lower side of the stub. A certain amount of gum flow occurs and the exudate accumulates in the crevice, often filling it. During dry weather especially this gum solidifies and presents an impenetrable barrier to the young larvae. For a while they subsist on bark fragments outside the gum barrier, but eventually die from starvation or the attacks of enemies. When rain falls within a few days after pruning the gum exudate may be partly leached away, and if wet weather continues the leaching is such that the gum barrier is ineffective and larval establishment can occur.

Pruning, therefore, should always be done with the greatest of care, in order to restrict egg-laying on the cut surfaces to a minimum, and be carried out during dry weather so as to obtain the greatest possible benefit from the gum exudation.

Disposal of Thinnings.

Thinning operations are essential in the management of hoop pine plantations. The residue of these thinnings provide suitable breeding material for many kinds of insects, including the pine bark weevil, which is one of the first to appear. The importance of the thinned stems in the population build-up of the pine bark weevil is, therefore, self evident.

The use of thinnings as decoy and trap trees might be practicable. Beetles remain in association with these trees for at least three weeks after felling. If the plantation were thinned a week in advance of pruning the fallen stems would attract and bind the greater proportion of any resident weevil population that might be active at the time and thereby limit the amount of oviposition on the pruned trees. The thinnings, having received the bulk of the eggs, could then be considered as trap trees and the stems removed for commercial purposes. Plantation practices so far have been better served by pruning before selecting the trees for the first thinning. If this method is to be continued this thinning should be done concurrently with pruning. Log lengths required for utilization could be cut off in readiness for later removal. At the same time, thinning residues such as tops and uncommercial stems could be slashed so as to provide maximum attraction for the weevil population. The commercial boles could be removed between a fortnight and a month later, by which time saw cuts on pruned trees would no longer be attractive to the weevils.

Tubing Routine.

Normal tubing routine would completely prevent attacks on tubed plants such as have occurred in the Gadgarra nursery.

Natural Control.

The abundance of a native insect is partly dependent on the prevalence and effectiveness of any natural enemies which might be operating against one or several of its developmental stages. In the pine bark weevil, egg, larval and pupal stages all possess some degree of protection from enemies. The egg, although deposited on an open wound on the host, is usually placed in a depression and enclosed by a hard cover. The larvae are internal feeders and, therefore, out of the range of any but the most specialized enemies. Pupae are located in the host tissues and embedded in a cocoon. However, most insects, no matter how specialized their habits, suffer from parasites and predators, and the pine bark weevil has several enemies.

Enemies of the Egg.

The egg, although provided with a hard cover, has two enemies—a parasite and a predator. The former, a Chalcidoid, is apparently ineffective, for numerous egg collections in the plantation yielded only a few individuals.

The activity of the adult Clerid predator *Stigmatium ventrale* Macl. (Plate 23, fig. 6) is more noticeable. This insect usually tears away the protective egg cover and then devours the egg. Sometimes a brown stain in an excavation on the wood surface indicates where an egg had been laid and subsequently attacked, but frequently no such sign of predator activity can be seen. Consequently, egg counts in the plantation do not give a satisfactory estimate of the effectiveness of this predator. The Stigmatium beetles are particularly agile and are capable of covering extensive areas. When numerous they apparently cause an appreciable reduction in egg numbers, but frequently some of the eggs on a stub are left untouched. The effect on the subsequent pine bark weevil larval population as shown by the amount of larval establishment in wounds was, however, not great and this predator is, therefore, of little economic importance.

Eggs collected in the plantation were sometimes attacked by an entomogenous fungus of the genus *Isaria.* Only about 2 per cent. were affected and then only in material collected during moist weather. In the laboratory, large colonies of saprophytic mites were often present in the breeding tubes but they only fed on eggs when these were first damaged by some other agent.

Enemies of the Larva.

Although the larvae of the pine bark weevil are apparently well protected within the tissue of the host, it is in this stage that the toll of natural enemies is greatest. This is due mainly to two larval predators—*Alaus prosectus* Cand. family Elateridae (Plate 23, figs. 4 and 5) and *Helina calyptrata* Mall. family Anthomyidae (Plate 23, figs. 1, 2, and 3).

A larval predator such as *Alaus prosectus,* provided with formidable jaws and capable of actively burrowing in search of its prey, has a definite advantage over the host. It easily penetrates existing tunnels and the host has only limited possibilities of protecting itself. However, Alaus larvae are common only in thinnings and show a preference for any longicorn larvae present; therefore attacks on the pine bark weevil are never extensive.

The most effective enemy of Aesiotes is the larva of an Anthomyid fly, *Helina calyptrata,* which, unusually for this family, is predatory. The adult fly presumably deposits eggs in the region of tree injuries where young larvae

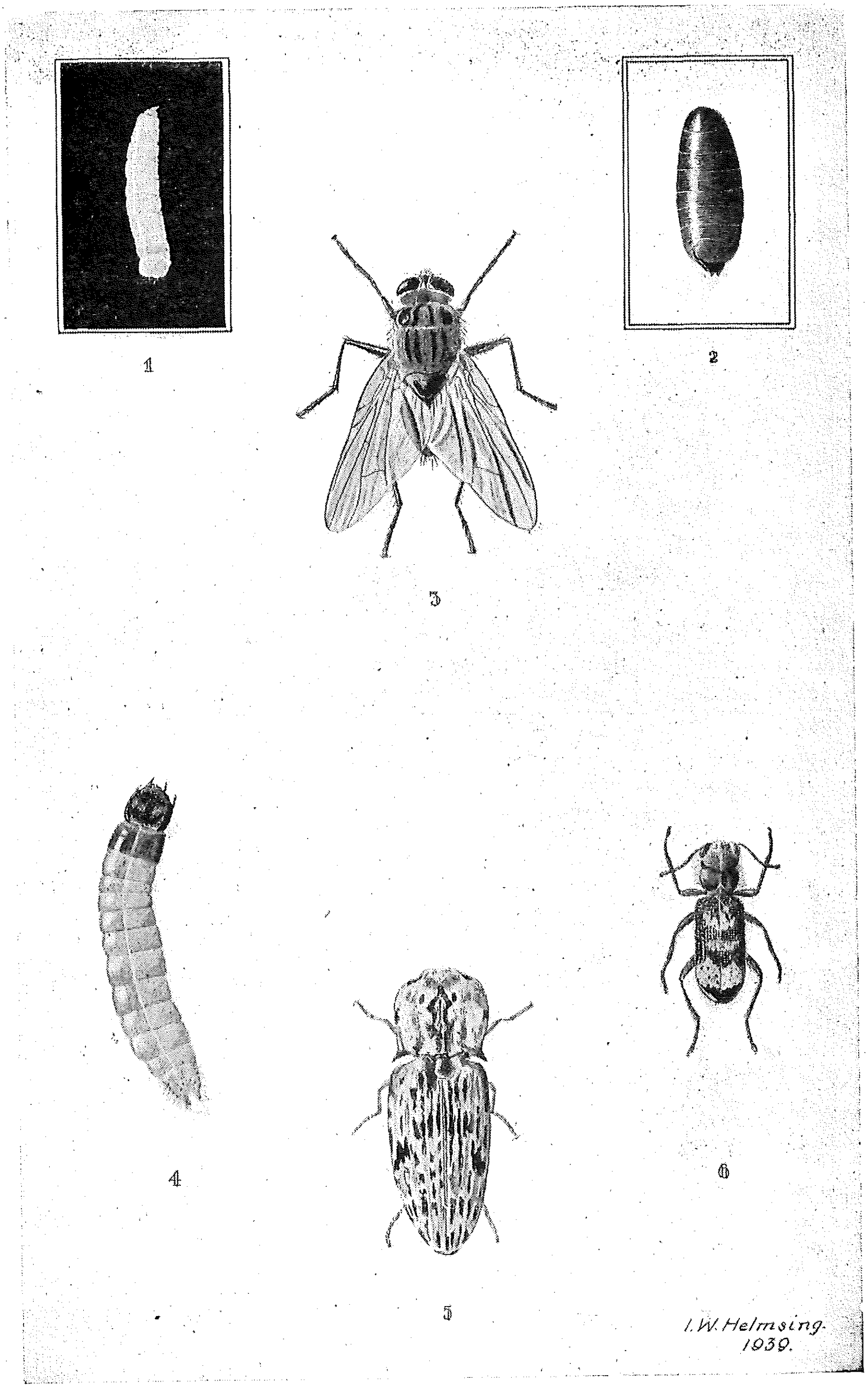

Plate 23.

Insect predators of the pine bark weevil. Fig. 1, larval stage of *Helina calyptrata* × 4; fig. 2, pupa of *Helina calyptrata* × 4; fig. 3, adult of *Helina calyptrata* × 4; fig. 4, larval stage of *Alaus prosectus* (natural size); fig. 5, adult of *Alaus prosectus* (natural size); fig. 6, adult of *Stigmatium ventrale* × 5.

of the pine bark weevil have just entered. After emergence, the young maggot seeks out the larval host and pierces the body wall with its oral stylets. After forcing its head into the host the predator remains in this position for some time, feeding on the internal tissues. Several host larvae may be attacked by a single Helina. The young Helina larva is very small and is capable of attacking only small pine bark weevil larvae. As it increases in size larger larvae are also attacked. In the laboratory, fly maggots, in the absence of young host larvae, were induced to attack the fourth and subsequent instars, but the host frequently proved capable of adequately defending itself. It is assumed, therefore, that in the plantation this predator is most effective against the earlier instars of the pine bark weevil. Larvae of *Helina calyptrata* appear to be restricted to the pine bark weevil, for attacks have not been observed on other weevil or longicorn larvae either in the plantation or in the laboratory. The economic importance of this insect has not been accurately estimated. Maggots held in the laboratory were voracious feeders, one individual killing and feeding on 20 second- and third-stage pine bark weevil larvae in six days. In the plantation, pine bark weevil larvae were very scarce on thinnings in which Helina larvae were located. Larvae of Helina are present in the plantation practically throughout the year, and the short larval period of five to six weeks suggests that this predator must exercise a marked effect on the density of pine bark weevil populations.

Pine bark weevil larvae attack each other when in close proximity, until one grub escapes or dies. Such behaviour is typical of crowded young larvae and as injuries frequently prove fatal this may reduce competition for the available food supply in the event of heavy egg-laying and hatching.

Mites of the family Parasitidae occasionally crowd around the hind and lateral margins of the head capsule and in body folds of pine bark weevil larvae. Usually they do not have any noticeable detrimental effect. They have not been observed to prevent successful completion of the larval stage, but individuals carrying a heavy infestation are generally undersized.

An entomogenous fungus, *Isaria* sp., occurs on larvae in the plantation, and occasionally individuals taken from field collections and established in the laboratory died from the attack. Some larvae also succumbed to what appeared to be a watery wilt, probably of bacterial origin.

Enemies of the Pupa.

The larvae of *Alaus prosectus* and the entomogenous fungus *Isaria* sp. are capable of attacking pine bark weevil pupae as well as the larvae. The Parasitid mites also occurs on pupae, and heavy infestation occasionally causes death.

Enemies of the Adult.

Attacks by the Isaria fungus on pine bark weevil adults have been observed, but only to a very slight extent. The Parasitid mites also mass about the eyes and between the abdominal sterna, but appear to be of little consequence.

Lizards and insectivorous birds are often seen in locations where pine bark weevils are present, but no attacks by them have been observed. There is, however, some small animal, possibly a rodent or marsupial, partial to the beetles. At all events, excreta of the rodent type is frequently associated with beetle remains in locations which adults frequent at night. The animal is probably nocturnal in habits and it devours the abdomen only, though in doing so the whole body of the beetle is dismembered.

The various natural enemies of the pine bark weevil probably destroy an appreciable number of individuals and cause some reduction in the adult population in plantations, but, as has been shown, plantation populations are always fairly high.

THE IMPORTANCE OF ASSOCIATED INSECTS.

A number of other insects are associated with pruned hoop pine trees in the plantation and some are of economic importance; however, with standard sylvicultural practices none of these is likely to become serious.

A Scolytid beetle, *Hylurdrectonus piniarius* Schedl., is attracted to any freshly-cut surfaces on living trees. It is very numerous in plantations, and beetles are present within a few minutes after a tree is pruned, while as many as 37 have been collected on or about a single stub an hour after pruning. Tunnelling commences anywhere in the extra-cambial tissue of the wound. In common with other Scolytidae, the adult beetles excavate tunnels and lay their eggs well within the bark where the progeny feed. The attack lasts for one generation only, which is completed in from four to six weeks. The tiny larvae tunnel mainly in the cortex, although development can be completed in the phloem. The amount of injury caused by each grub is negligible, but usually large numbers are present and the aggregate effect may be appreciable. The tunnelling by both adults and larvae accelerates the breakdown of tissue about the stubs, which increases the amount of lifting of the bark from the wood and thereby assists the entry of pine bark weevil larvae.

The larval stages of four other insects are associated with pruned trees, but their attacks do not develop until after the Aesiotes and Scolytid phases have passed. They are *Syllitus araucariae* McK. and *Temnosternus imbilensis* McK. family Cerambycidae, an unidentified Buprestid, and an unidentified Curculionid. The larvae of *S. araucariae* live only in dying tissue and are therefore confined to a small ring of bark about the apex of the stub. The Buprestid larvae tunnel between the dying bark and the wood. Attacks by both of these insects are usually preceded by Scolytid infestation, which increases the amount of bark injury in the vicinity of the stub. As these insects do not attack living tissues, they are not of great economic importance. The larvae of *Temnosternus imbilensis* and the unidentified weevil are located mainly at the lower side of the stub. They normally feed on dying tissue only, but may penetrate into living tissue. The bark on the lower side of the infested stub usually dies back to the sapwood of the bole when these insects are present and occlusion then must cover a much larger area. Rain water often collects in the pockets made below the stubs and induces a stain in the wood. Sometimes decay of the surrounding bark follows and the damage may become as serious as that caused by a pine bark weevil larva.

Many species of insects are associated with hoop pine thinnings. Large numbers of larvae of the Trypetid *Rioxa araucariae* Tryon and an undetermined Stratiomyid congregate under the lifting bark and set up a wet rot which makes conditions unsuitable for pine bark weevil larvae. A Cerambycid, *Diotima undulata* Pasc., and a Curculionid, *Illacuris laticollis* Pasc., can attack thinnings anywhere along the bole. Usually they are very numerous and also adversely affect the development of the pine bark weevil. The remaining insects normally do not attack the thinnings until the Aesiotes phase is well advanced or past.

CONCLUSIONS.

Early attempts at green pruning hoop pine, *Araucaria cunninghamii,* in the Mary Valley plantations were followed by attacks of the pine bark weevil, *Aesiotes notabilis* Pasc. In addition to hoop pine, other native species of *Araucaria,* species of *Agathis* and several exotic conifers of the genus *Pinus* are hosts.

The pine bark weevil is essentially a rain-forest species, the distribution of which corresponds with that of tropical and subtropical rain forests with species of *Araucaria* or *Agathis* as components.

Attacks by Aesiotes are initiated in open wounds shortly after they are produced. Such wounds are rare on trees in the natural rain forest, where the insect is of little economic importance. In plantation practice, the lower branches, both living and dead, must be periodically pruned from established hoop pine. The prune cuts are attractive to the pine bark weevil. Attacks on pruned trees are accompanied by the ejection of frass from the pruned stubs and a dark, gum-like seepage down the trunk. Eggs are laid on the stubs. The young larvae enter the cambium and penetrate to the bole of the tree, where they continue to feed on the inner bark. Tunnelling encircles the base of the stub, where the bark is relatively thick, and if the larvae are numerous may spread along and round the bole. The tree may die, but more usually the slow occlusion of the injury results in an unevenly-shaped bole. Larvae entering the pith of stubs fail to develop, but some feeding takes place and rain water collecting in the upwardly pointing cavities promotes wood rots.

Oviposition is mainly nocturnal. In the plantation, eggs are almost invariably laid on or near freshly injured bark and each is then covered by material which sets into a protective cover. Adults may live for 18 months or more and can continue egg-laying for the greater part of this period. The maximum number of eggs laid by a single female in the laboratory was 749.

In the laboratory, both food and temperature influence the rate and amount of oviposition. Reproduction is high at temperatures between 20·0 deg. C. and 28·0 deg. C. when fresh bark is supplied as food. Except in winter, plantation temperatures normally fall within these limits.

The incubation period in the laboratory varies from 7 to 10 days. Complete hatching is usual in eggs held between 12·2 deg. C. and 32·2 deg. C., but the sigmoid velocity "curve" indicates a threshold of development at 4·0 deg. C. Incubation is most rapid at relative humidities from 90 per cent. to 100 per cent. and in the temperature range from 25 deg. C. to 27·0 deg. C. Hatching is at a maximum in a saturated atmosphere and decreases with the humidity to zero point at 17 per cent., but the mortality is not great at humidities above 50 per cent. Monthly mean relative humidities in the plantation were never below 50 per cent. during these investigations, and as plantation temperatures are normally favourable hatching can take place throughout the year.

In the laboratory, establishment of newly emerged larvae in the phloem occurs at all temperatures from 10·2 deg. C. to 34·8 deg. C. The period of survival without food is, however, longest in saturated atmospheres, and humid conditions in the plantation would therefore be required to allow a sufficient period in which the larvae can locate and penetrate the injured bark. Temperature exerts a marked influence on the length of the larval period, which is shortest between 24·0 deg. C. and 25·0 deg. C., when it requires approximately 55 days. The number of instars may be five or six and the variation cannot be assigned to food or sex. Dyar's Law cannot be used in determining the instar or the number of instars of the larvae.

The pupal chamber is a boat-shaped depression in the surface of the wood. In constructing it, the larva peels the wood away in thin, flat strips which are compacted to form a cocoon over the pupal chamber. The mean pupal period is 13·4 days. Development is most rapid at relative humidities between 74 per cent. and 95 per cent. In this humidity range the minimum pupal period of 9 days occurred at 30·2 deg. C.

The freshly emerged weevil remains in the pupal chamber for a period of about 12 days before leaving the host. The adults then may mate, but the average oviposition rate is not attained until about 7.5 weeks later. A mean period of 36 days elapses between the cessation of laying and death. The pine bark weevil is both polyandrous and polygamous.

Adults normally feed on both the phloem and cortex of freshly cut bark but may subsist for a limited period on foliage. At all experimental temperatures below 30·0 deg. C. they outlived a test covering 132 days. Above this temperature death soon took place. The threshold of adult activity is shown to approximate 0·0 deg. C.

Adult flight has been observed once only, but evidence indicates that it must be common in the plantation.

Adult pine bark weevils are present in the plantation throughout the year. Life history observations indicated a life cycle of about three months in the summer and five to seven months over the winter months. The life cycle in the laboratory requires a minimum period of 92 days at 25·0 deg. C., and lengthens with fall in temperature. This is in agreement with plantation records.

In an attempt to prevent pruned stem cuts from becoming infested by pine bark weevil larvae, the cut surfaces were experimentally treated with a number of chemicals. However, economic attacks did not eventuate on either treated or untreated trees and the efficiency of the materials could not be determined. Some materials, such as creosote and coal tar, inhibited gum exudation and prevented oviposition by Aesiotes. Copper preparations stimulated undesirable exudation of gum. Adhesive bands placed above and below pruned stubs did not prevent egg-laying.

Natural enemies operate against each life stage of the pine bark weevil. An entomogenous fungus of the genus *Isaria* occurs on all stages, but the proportion of insects killed is small. Predatory mites are sometimes present in large numbers on the larva, pupa and adult, but have little effect.

A Clerid, *Stigmatium ventrale,* feeds on pine bark weevil eggs in the plantation and may sometimes cause a considerable diminution in numbers. Larvae of an Elaterid, *Alaus prosectus,* prey on both larvae and pupae in thinnings, but prefer longicorn larvae when these are present. The larva of an Anthomyid, *Helina calyptrata,* is more important. It causes an appreciable reduction in numbers, but attacks only the earlier larval stages. What is presumed to be a carnivorous rodent or marsupial preys on the adult beetles. The total effect of natural enemies on pine bark weevil populations could not be evaluated but must be appreciable.

Laboratory studies have shown that egg-laying is greatest and development most rapid in a humid atmosphere and field observations indicate greatest adult activity in moist weather. Pruning and thinning operations should, therefore, be carried out when dry weather is normally expected, i.e. in winter and early spring. Pruning should always be done with sharp saws in order to leave clean and even cut surfaces and to avoid injuring the main stem. Thinnings serve as breeding grounds for Aesiotes. Thinning operations may be combined with pruning in such a way that the discarded stems both attract and bind the adult population, thereby affording protection to the pruned trees.

Winter pruning and early spring pruning of hoop pine are not accompanied by Aesiotes attacks of economic importance. Minor damage is, however, associated with jagged wounds and slight lifting of the injured bark, mainly on the lower side of stubs, but for the most part the accumulation of gum exudation therein forms an impenetrable barrier to larval infestation in the bark.

REFERENCES.

ANDREWARTHA, H. G. 1933. The bionomics of *Otiorrhynchus cribricollis,* Gyll. Bull. Entom. Res. 24: 373-84.

BAKER, R. T., and SMITH, H. G. 1910. A research on the pines of Australia. Sydney.

BIRCH, A. J. 1938. Note on the exudation of *Araucaria bidwillii.* J. Roy. Soc. N.S.W. 71: 259-60.

DAVIDSON, J. 1942. On the speed of development of insect eggs at constant temperatures. Aust. J. Exptl. Biol. Med. Sci. 20: 233-39.

DYAR, H. G. 1890. The number of moults in Lepidopterous larvae. Psyche 4: 420-23.

FIDLER, J. H. 1936. On the first instar larvae of some species of *Otiorrhynchus* found on strawberries, with notes on their biology. Bull. Entom. Res. 27: 369-76.

FRENCH, C. 1911. A handbook of the destructive insects of Victoria. Part V. Melbourne: Government Printer.

FROGGATT, W. W. 1923. Forest insects of Australia. Sydney: Government Printer.

__________. 1927. Forest insects and timber borers. Sydney: Government Printer.

JANISCH, E. 1932. The influence of temperature on the life history of insects. Trans. Entom. Soc. Lond. 80 (2): 137-68.

MCDOUGALL, W. A. 1934. The determination of larval instars and stadia of some wireworms (Elateridae). Qld. Agric. J. 42 (1): 43-70.

PALM, C. E. 1935. The alfalfa snout beetle, *Brachyrhinus ligustici* L. Cornell Agric. Expt. Sta. Bull. 629.

PASCOE, F. P. 1865. On some new genera of Curculionidae, Part I. J. Entom. 2: 413-32.

PATERSON, A. 1938. The occlusion of pruning wounds in Norway spruce (*Picea excelsa*). Ann.Bot. n.s. 2 (7): 681-98.

TSAI. P. H. 1935. Epidemiological experiments with the paddy borer. I. The influence of temperature and relative humidity on oviposition and hatching. Agric. Sinica 1 (9): 273-317.

ERRATUM.

A soldier ant belonging to the genus *Pheidole* was inadvertently included in Plate 2 of the paper ''Seed-harvesting and other ants in the tobacco-growing districts of North Queensland'' which appeared in Volume 1, Number 3 of the Journal. Ants in the genus *Monomorium* do not possess a soldier caste.

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