FORESTRY COMMISSION

BULLETIN NO. 16

STUDIES ON

THE PINE SHOOT MOTH

(*Evetria buoliana* Schiff.)

LONDON: HIS MAJESTY'S STATIONERY OFFICE

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PREFACE

An attempt has been made in Part 1 of this Bulletin to bring together all the manuscript dealing with studies on the biology and forest relations of the pine shoot moth, *Evetria buoliana* Schiff, left in an unfinished state by the late Mr. C. C. Brooks, who lost his life as the result of a motor accident in June, 1930. The material, which was incomplete in some respects, has been edited by Dr. R. N. Chrystal of the Imperial Forestry Institute, Oxford.

Since the commencement of the task further data have been collected by Mr. J. M. B. Brown on the distribution of the moth in East Anglia and on the results of recent experimental control studies. These have been dealt with in Part 2, and the results shown there to some extent round off the research work left unfinished by Mr. Brooks.

R. L. ROBINSON,
Chairman

FORESTRY COMMISSION,
9, Savile Row,
London, W.1
July, 1936

PART 1

THE BIOLOGY AND FOREST RELATIONS OF THE PINE SHOOT MOTH

by the late

C. C. BROOKS, M.Sc.

PART 2

THE STATUS OF THE PEST IN EAST ANGLIA AND EXPERIMENTS ON CONTROL

by

J. M. B. BROWN, B.Sc.

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PART 1

THE BIOLOGY AND FOREST RELATIONS OF THE PINE SHOOT MOTH.

INTRODUCTION

DURING the past few years the Forestry Commission's plantations in East Anglia have suffered severely from the ravages of the pine shoot moth, *Evetria buoliana* Schiff., and, as the attack showed no sign of abatement and the usual preventive measures had proved either impracticable or useless, an investigation was commenced in August, 1928, at the Imperial Forestry Institute, Oxford.

The ecology of the Brecklands in East Anglia, where the areas are situated from which most of the data given in this Bulletin have been obtained, has been well analysed by Farrow in a series of papers published in the Journal of Ecology from 1915 to 1925. The natural dominant vegetation of this region appears to be low pine wood, and it appears probable that this type persisted from Neolithic times until about the end of the Middle Ages.

Shortly after the Norman Conquest, however, according to most authorities, and certainly in historical times, the rabbit was introduced into England and, though originally kept semi-domesticated in warrens on account of the value of its fur, it soon became wild and spread rapidly. As every forester knows, rabbits are exceedingly harmful to the natural regeneration of forests, and although an equilibrium would soon be struck with their carnivorous enemies, stoats, weasels, etc., they evidently succeeded in entirely changing the vegetation of the Brecklands. The pine woods disappeared and were replaced by heather, which in turn gave place to rush or grass heath according to the nature of the soil, when the rabbit population rose above a certain density.

The deteriorating effect upon the soil of these changes in the vegetation can well be imagined. Instead of the previous gradual accumulation of humus under a comparatively dense protective canopy rapid denudation took place, for East Anglia has the most continental type of climate in the British Isles, and during dry summers the winds have blown away most of the very alkaline sandy soil from the unprotected land covered only with close-cropped grass, so that in extreme cases in exposed situations the soil remains mixed with flint boulders, less than four inches deep over a substratum of chalk. In such places lichens are the only vegetation which can live satisfactorily.

A further complication has arisen owing to the invasion of large areas of the better quality land by bracken which is not eaten by rabbits, and has thus been permitted to thrive where it is not cut back in forestry operations to prevent its smothering the young trees.

Of the reintroduction of Scots pine into the area there is little definite information but, according to local tradition, agriculturists just over a century ago were forced to plant shelter belts of this tree around their fields as a protection from the winds. Certainly such shelter belts are characteristic of the countryside today. It seems probable that these pines were of Scottish origin, and if so it is unlikely that it was with them that the pine shoot moth was introduced into the area, as the insect was very rare in that country. However, traces of the pest's attack have been observed in trees in these belts, showing that it was present at least fifty years ago, and has been breeding in insignificant numbers ever since. Whether it had spread from other parts of England, or had been introduced from the Continent, or both, cannot now be ascertained.

SYSTEMATIC POSITION

The Genus *Evetria,* Hübn., is placed by Meyrick (1927) in the family *Eucosmidae* of the phylum *Tortricina* and contains about forty species, all of which are confined to the temperate regions of the northern hemisphere. Seven species have been recorded from the British Isles.

The larvae usually feed on species of *Pinus,* but one North American species, *E. taxifoliella* Busck, has been recorded from *Pseudotsuga douglasii.* They are to be found in the buds, the shoots, the bark and in galls and seem to prefer young trees. Most species, especially those native to North America are confined to one or a few species of host plant (Busck).

One generation a year, with hibernation taking place in the larval stage, is the usual life cycle, but in northern regions this may be prolonged in some species to two years and in the warmer regions of the Mediterranean and the United States species or varieties occur which have two or more annual generations.

Many of the species are of little more than academic interest, being restricted in their geographical distribution and in the species of host plant they attack, but some are of great economic importance and are important pests in the pine plantations of the north temperate zone.

GEOGRAPHICAL DISTRIBUTION

Evetria buoliana Schiff., has been recorded from pine-growing areas in all parts of Europe, Asia Minor, Siberia and Japan, and has recently been introduced into North America where it has become acclimatised and is still spreading. It becomes rare, however, in northern England and has so far not been recorded from the north of Scotland. Its adaptability to geographical changes, together with the fact that it attacks almost indiscriminately all species of the genus *Pinus* and its great fecundity in suitable situations, have caused it to be recognised as one of the most important pests of pine plantations over its wide range.

Over the southern part of its distribution, in the south of Spain, Corsica and Palestine, a variety, *E. buoliana* var. *thurificana,* Led., has adapted itself to the warmer climate and has acquired an annual cycle of two generations. This greatly increases the significance of the introduction of the pest into America and confirms Busck's fear that in the more southern States it may develop a second generation, as most of the native species have already done, and so become doubly injurious in its attacks.

As to whether the species is indigenous to Great Britain there is little direct evidence. No mention is made of it in the literature nor has correspondence with several botanists and geologists who have worked on the peat deposits in this country brought to light any record of finding the typically deformed trunks of pine trees preserved in this medium. There are, however, a few facts which bear on this question.

Another species of *Evetria, E. pinicolana,* which differs from *E. buoliana* by having a more arched costa, is found in the British Isles and is not recorded elsewhere. It was at one time regarded merely as a variety of *E. buoliana,* but the differences in the genitalia separate the two as distinct, though closely allied, species. At the conclusion of the Ice Age, as the snows retreated northwards they were closely followed firstly by forests of birch and secondly by Scots pine and it is possible that the original *buoliana-pinicolana* stock passing northwards with the latter vegetation became divided by the North Sea, the first and smaller portion in northern England and Scotland and the larger portion in the pine belt of the Continent. They would then, with isolation, evolve into two closely related species. This hypothesis is further borne out by the fact that biologically continental forms are found virile and active while island forms are generally sluggish and unadaptable; a fact that is well illustrated in the two species under consideration. This would point to the supposition that *E. buoliana,* indigenous to the Continent, has been introduced to England by man in late historical times in plants imported from the Continent and that, while it has become established and acclimatised in this country, especially in the artificially planted areas in the south, it has not yet colonised the northern parts of these islands.

HISTORICAL SUMMARY

Evetria buoliana was first described in 1776 by Schiffermiller, as *Tortrix buoliana,* the specific name being given in honour of a Viennese entomologist, Baron Buol, who studied the insect's depredations during the latter part of the eighteenth century. One of the earliest European outbreaks recorded was that of 1805–07 in Denmark, which was of such severity as almost to cause a cessation of pine planting in that country. Wholesale pruning and burning of infested shoots were recommended as control measures at this time, and these have remained standard ever since. In 1838, Hartig in Germany bred fifteen species of parasites from infested shoots, and suggested that such shoots might be placed in cages in spring, the cages being covered with a wire netting the mesh of which would be large enough to allow parasites to escape, but not the moths.

In 1840, and again in 1866, Ratzeburg, the well-known German forest entomologist, gave a detailed account of the biology of the species and discussed its economic importance and control. Judeich and Nitsche in their text-book of 1895 brought Ratzeburg's work up to date. From 1895 to the end of the century we get references to the species from Holland (Louink and Ritzema Bos), France (Severin), and Denmark (Boas). The first thirteen years of the new century (1900–13), produced two important papers, those of Barbey in 1912 and 1913, and Rodzianko in 1913. Barbey advocated mixed planting as an economic control measure, while Rodzianko, who had studied severe outbreaks of the insect in the neighbourhood of Kieff, urged the importance of spring pruning of infested shoots, and also noted the occurrence of caterpillars and pupae in the male flowers on the crowns of tall trees.

In 1914 and 1915, A. Busck of the United States Department of Agriculture, Bureau of Entomology, published two papers recording the presence of the species in various parts of North America. Importation of pines from Europe into the United States had been going on for a number of years, and it was presumed that hibernating caterpillars must have been introduced into the country on this stock. Once introduced, the insect started to attack the native species of pine, and study of its habits showed that the climatic conditions would favour two generations per annum and thus render the species doubly devastating.

Intensive handpicking of infested buds and shoots was at once undertaken, and the United States Department of Agriculture issued an ordinance forbidding the importation of pine trees from Europe after July 1st, 1915. Busck, in his 1915 paper, found the habits of the caterpillar stock introduced into America similar to those of the European stock. Both concentrated their attack upon pines between the ages of six and fifteen years, the nature of the damage done being similar, and severe attack on trees over thirty years old of rare occurrence. The climatic conditions in America, however, allowed the caterpillars to destroy more than one bud before they went into hibernation, which does not usually occur in Europe. In July, 1917, Canada followed the lead of the United States, by issuing a quarantine ordinance against *E. buoliana,* forbidding the importation of pine nursery stock from Holland and France. This ordinance, coupled with that of the United States, had far-reaching effects in both Holland and France, where in many districts nursery work of this kind had to be abandoned.

In 1917, Vilmorin, a French entomologist, recorded finding parasite cocoons in the caterpillar's galleries, and also within the bodies of young caterpillars. This led him to revive Hartig's original suggestion of putting infested shoots in cages and facilitating the release of parasites. In 1918, Smits van Burgst, who also had bred a number of parasites of the species, brought forward some cogent reasons why it would be unwise to place too much reliance upon parasites effecting control. In the same year, Jolyet called attention to the value of bats, especially those of the genus *Vesperugo,* as agents in natural control.

In 1919, Munro in his survey of insect conditions in the British Isles, a work undertaken for the Forestry Commission, cited *E. buoliana* as a very destructive species but expressed grave doubts of the practicability of any control measures, and correlated severity of attack with poor soil conditions.

From 1920 to 1928 more than a dozen papers were published, but only a few of these need be cited here. Boas' paper of 1923 is interesting as following up his earlier work in Denmark. He discussed the spring habits of the insect, and again advocated the release of parasites from special cages. In 1925 and 1926, Gasow published two important papers. He described the egg-laying and hatching in detail for the first time, and pointed out the possibility of using an insecticidal treatment at this time. He also showed that the caterpillars usually spend the winter in the side buds, but he did not connect this habit with any mechanical control measure such as disbudding. About the same time, Nechleba, discussing the structural damage done by the insect to the pine, pointed out that pseudo witch's brooms in pine trees resulted from a single primary feeding, and gave excellent illustrations of these in his paper. In 1925 and 1926 further papers appeared in the United States and Canada showing the progress of the insect's attacks. Heinrich, in the United States, showed that despite the control measures which had been put into effect, the insect still persisted and was only being being held slightly in check. In Canada, McLaine and Hutchings showed that the insect had been discovered in 46 different localities and that for some twelve years it had been well established.

In 1927, Bodenheimer, working in Palestine, described a variety of the species, *thurificana* which showed two generations per annum. This phenomenon he ascribed to the higher average daily temperature and concluded that those localities in which average daily temperature added up to over 7,000 deg. F. per annum, might also produce a similar life cycle. This has importance for America, but none for Britain. Finally, in 1928, just about the time of the commencement of the present work, Ryle published a brief essay on the pine bud and shoot moths in England. Most of the observations upon which this essay was founded were made on the same areas which have been visited in connection with the work described in this paper.

DESCRIPTION OF THE MOTH

The description of the adult (Plate I, fig. 1) is as follows*:—
Head and face sulphur yellow. Eyes black. Palpi orange red, longer than the head, paler at the base in between. Antennae shiny with marked light and dark grey bands, brownish towards the base. Thorax pale glossy grey in front and behind, darker orange on the vertex. Patagia bright orange red at the base, glossy greyish white at the apex. Fore wings bright orange red slightly paler at the base with transverse silvery streaks and spots, the number and disposition of which are exceedingly variable, the silvery markings are sometimes thickly irrorated with grey. They have a lustrous appearance when viewed directly which turns to dead white when viewed obliquely. The costa of the fore wing slightly arched. Scales on the wing margins dense and silvery and tipped with iron grey with a definite dark line at the base, which is continuous along the whole length of the fringe. Hind wings dark fawn clothed with coarse scales. Marginal scales light grey with a dark continuous line at the base similar to the fore wings. Abdomen grey, shiny. Caudal tuft with a very pale pinkish tinge. Wing expanse 18–22 mm.

LIFE-HISTORY AND HABITS

The moths fly in the evening, remaining quiescent during the greater part of the day, and when disturbed taking only short darting flights until they again reach shelter. Slight activity occasionally manifests itself about midday. In the evening they fly in a slow hovering manner with rapid beating of the wings. Pairing usually takes place in the evening following emergence, and apparently occurs only once for both sexes, although the males have been known to live for fifteen days after pairing. The moths have never been observed to feed in captivity, although fresh raisins, split raisins, honey, and sugar and water were provided for them in cages. The chief interest of the adult's life centres around oviposition. Examination of the ovaries of a well-developed female shows that it is theoretically capable of laying about 700 eggs, but practically speaking, from counts made of the number of moths emerging from a hundred trees in a sample plot and the number of eggs laid on a similar unit in the same situation the following month, it was found that the average number laid by each female was about 76. This estimate disregards the number of moths which die before egg-laying but gives a fair idea of the average reproductive capacity of the species.

The maximum length of the adult female's life is about three weeks. The eggs are usually laid singly, but occasionally in twos and threes, on the bark of the young shoots while still green. They are sometimes found on the buds and very rarely on the needles. They are often placed in a crevice or are sheltered by the needle sheaths. Gasow states that the eggs are never found more than 3·5 cms. away from the bud and assumes that this is an adaptation to facilitate the establishment of the larva in the buds. He and several other workers have considered that the newly hatched larva is very weak and incapable of crawling even a short distance. This supposition is not borne out by an experiment in which a newly hatched caterpillar was kept alive, without food, for six days, during which time, judging from the length of the continuous silk thread it had spun, it had crawled a distance of nearly a quarter of a mile! Caterpillars have also been known to establish themselves in bud whorls other than the one of the shoot upon which the egg was laid. In fact the capacity

* This description is based on that of S. J. Wilkinson, *British Tortrices*, London, 1859. It has been modified, however, in several particulars.

for moving about which the caterpillars possess in all their stages has been greatly under-estimated by all previous workers. Eggs have also been found laid within 3 inches of the base of an 18-inch shoot, while they are quite commonly laid 6 to 9 inches from the buds. The only limiting factor for their situation appears to be that the moth is greatly attracted for egg-laying purposes to the fresh green bark of the young shoot before it begins to turn brown. The emergence of the moths coincides with the hardening and consequent changes in colour of these shoots. This hardening of the shoots is comparatively rapid, beginning from the base upwards, so that while the first moths to oviposit have the choice of practically the whole shoot, those laying their eggs a few weeks later find themselves restricted to the very apex of the shoot.

The distribution of the eggs upon the trees throughout the plantations is uneven. Trees above the average height are almost invariably found with an excessive number of eggs upon them. This is to be expected, as, if egg-laying is merely a random operation on the caterpillar's host plant, the chances are greater of the moths flying against and ovipositing upon a prominent tree than on one of less than average height. This is of great economic importance as it causes the dominant trees in a plantation to be, on the average, more badly attacked than the dominated trees. For the same reason the top branches of the trees are attacked to a greater extent than the lower ones, and it is interesting to note that on two adjacent plantations, one eight, and the other six, years old, where the numbers of moths would probably be similar, the average populations per 100 trees were found to vary according to the superficial area of the shoots above the average height at which the thicket had closed in.

The average duration of the egg stage is about 14 days, and the young caterpillar on hatching immediately crawls away from the empty egg-shell and searches for food. Except on very green twigs, it seems to be incapable of penetrating the hard bark of the stem, but with the instinct of moving upwards rather than downwards, ascends the stem until it reaches the bud whorl where the first feeding takes place. Occasionally, however, the young caterpillar may first enter a needle-sheath and devour the softer tissue at its base, and this may be of evolutionary significance, as it is the normal method employed by the gall-forming member of the genus, *E. resinella*. Once in the bud whorl the caterpillar displays a marked tendency to withdraw itself into any cracks or crevices, such as the narrow spaces between the buds, however brightly illuminated these may be, and this habit is retained throughout its life. Here it may bite through the thin bud-scales and commence feeding at once upon the soft tissue within, but as a rule it first spins a protective web.

From the moment of hatching, the caterpillar exudes a silken thread. This thread, fixed at various points, is mechanically drawn out from the silk glands as the caterpillar moves about, or moves its head from side to side. If shaken from the twig, the caterpillar hangs down suspended by the thread and, if left undisturbed, is capable of reclimbing it. Once a suitable situation has been found in the bud whorl, the young caterpillar, raising the anterior part of its body and moving its head from one side of the crevice to the other, spins over itself a protective roof formed of hundreds of closely interwoven strands of silk. After about twenty minutes, when the roof is usually complete, the larva commences to bite through the bud scales and to bore into the soft tissue within. It also strengthens the web by plastering it with some of the tissue and resin masticated during the boring operations, the whole being strengthened by another layer of silk (Plate II, fig. 1). Where space allows, the walls and the floor of the crevice are treated in the same way, or are at least lined with silk. This process of lining the resin with silk is not done merely for comfort. It has practical importance in that it coagulates and hardens the sticky substance, which, if it came into contact with the caterpillar's naked body, would hold it fast with fatal results. The same method is applied to the actual food burrows in the living tissue. They are always found lined with a silken mesh to prevent resin from the damaged tissues oozing through.

The caterpillar continues to feed and enlarges the excavation in the bud. The frass and superfluous resin are plastered, bit by bit, on the web and lined with silk, and the continual journeyings to and fro compel the insect to enlarge the entrance hole as it grows. Often the old web is found to be too small; and is partially demolished, a larger one being spun in its place. The first moult takes place about three weeks after hatching. The cast skin is embedded in the web and the caterpillar continues feeding. Sooner or later, however, the food supply of one bud becomes exhausted. The caterpillar then either bores directly into an adjacent bud under the shelter of the same web, or abandons its habitation altogether and migrates to another branch. This does not, however, occur very commonly before the spring, except with those caterpillars which have established themselves first in the small whorls on the lower branches of the young trees. As a general rule, the caterpillars hibernate in the third larval stage, but they are sometimes found in the second, and more rarely in the fourth stage. As cold weather approaches they become sluggish and line the cavity, which is usually a spiral about the central axis of the stem, with a thick web. In many cases the entrance hole is also blocked up, and in the chamber thus formed, they pass the winter in a resting stage. An interesting point is the fact that the caterpillars established in any whorl of considerable size, and especially that of the large leading shoot, are almost invariably found in the lateral buds of the whorl during the autumn and winter. This may be due to an instinct to leave the most plentiful food supply until the period of ravenous feeding in the spring, or it may be that the small caterpillars are incapable of coping with the excessive amount of resin in the large central buds.

With the warmer weather of March and April, the caterpillars again become active, although spells of cold weather will cause them to relapse into torpor. They immediately moult, probably without any preliminary feeding, but after this they begin feeding in proportion to their increased size. They attack the larger buds and young shoots which are by this time commencing to grow (Plate II, fig. 2 and Plate III). Whole whorls may be destroyed and caterpillars may burrow down into the old wood below, while migration from branch to branch becomes common. The caterpillars continue to spin their webs and line their burrows with silk, and have the same tendencies as in their younger stages. Consequently, as their instinct is to ascend rather than to descend, migration will occasionally lead them to contaminate the whole whorl of leading shoots which were unattacked during the autumn. In connection with this migration, we may review Boas' observations on resinous galls inhabited by the caterpillars which were found in the forks of the older parts of the trees. He considered that they were abnormalities and that the stimulation to migrate and settle in such unaccustomed places was due to the irritation caused by internal parasites. It seems more probable, however, that these caterpillars migrated as a result of food shortage, and were unable to resist the instinct to inhabit the crevice in the fork of the branches, and therefore spun their webs and bored into the wood there. This is borne out by Altum's record of breeding the adults from such galls. Similar galls have been observed by the author on trees in fire-scorched areas which have had their shoots killed, but whose thicker branches were still alive.

No evidence is forthcoming to support Ryle's statement that the caterpillars sometimes inhabit the old tunnels of the pine shoot beetle, ***Myelophilus piniperda***. On the contrary, if a shoot inhabited by the *E. buoliana* caterpillar is attacked and killed by the beetle, the caterpillars invariably migrate either to the secondary buds which grow out below the entrance hole made by the beetle, or to another bud whorl.

Towards the end of June and the beginning of July, the caterpillars are full grown (Plate I, fig. 2). They now measure 21 mm. in length, and are dark reddish brown on the upper surface and light reddish brown on the under surface, with the head and prothoracic shield almost black. They cease feeding on the green portions of the shoots and withdraw into a bud or shoot which has been previously killed and has become quite dry. Failing to find such a situation, they choose a crevice, generally at the base of the whorl of shoots. Here they spin a thick web reminiscent of that of the hibernation chamber, and after a short time they pupate.

The pupal stage may be as short as twelve days, but during cold weather may last as long as five weeks. The average time is about sixteen days. For the greater part of this time the pupa is motionless, though if disturbed it is capable of moving the terminal abdominal segments. Just before the emergence of the adult this movement occurs naturally, and it is by this movement of the terminal abdominal segments that the anterior portions of the pupa are thrust out of the web. In some cases the pupa may wriggle itself clear of the web, and fall to the ground, but it is usually only the anterior parts of the body which are freed. In a few minutes the plates on the head and thorax split along the median dorsal line, and the moth rapidly emerges. Emergence usually takes place in the early afternoon. The moth, whose wings are as yet mere rudiments, crawls rapidly up an adjacent shoot or needle, where it rests while the wings develop. This they do almost to full size in the space of four to five minutes. The wings are then raised over the back for about a quarter of an hour to twenty minutes, while hardening continues, after which time they are lowered and folded over the abdomen in the normal manner. Unless disturbed, the insect will then remain motionless until the evening when the first flight takes place.

QUALITATIVE DAMAGE

As we have seen from the foregoing account of the life-history of the moth, its economic depredations are confined to the larval or caterpillar stage. The actual damage done to the trees falls into several distinct types:—

Physiological Damage

Loss of plant substance and assimilatory surface to the tree owing to the weakening or killing of the young shoots. This damage is usually negligible, but on poor soils and in other adverse conditions it may become important.

Structural Damage to the Timber due to Injury to the leading Bud or Shoot

This can be subdivided as follows:—

(*a*) The whole apical bud whorl may be destroyed. (Plate IV, fig. 1.) The result of this is that secondary axillary shoots grow out from below the injury, causing the "pseudo witch's broom" type of damage described by Nechleba. (Plate IV, fig. 2.) This damage is usually only caused whhen several caterpillars establish themselves in one bud whorl, but can be accomplished in one season, and need not be the result of successive attacks. These secondary shoots are incapable of sustained growth, and any great increase in height must come from the growth of one of the older side branches, which results in the disfigurement of the tree.

(*b*) The apical bud or shoot may be destroyed, but one or more of the lateral shoots of the whorl may be left intact. The result is that one of these lateral shoots will become the leading shoot. This may happen with either negligible or slight curvature, but sometimes when two side shoots are approximately equal, a fork may be produced. Here again, secondary axillary shoots often develop.

(*c*) The apical bud or shoot during early growth may be slightly gnawed on one side. The damage is insufficient to cause its death or breaking, but the wound exudes resin, which forms a hard cake, and only slowly calluses over leaving a rough scar, bare of needles. This results in the unequal growth of the shoot. The uninjured side grows more than the injured one and a bending towards the latter ensues. This damage is rarely of any great importance except in so far as it involves minor loss of height growth.

(*d*) The leading shoot may be badly attacked from the base during growth which results in a weakening of its mechanical support. The result of this is that in a gust of wind, or sometimes even with its own weight, the shoot falls over at the attacked point with a lateral " green stick fracture." The angle to which the shoot bends depends upon the amount of injury, and whether it falls towards or away from the injured side. If the latter, the fall is mechanically checked by tension on the hinge for it is still attached to the tree by enough tissue to allow it to keep alive. It continues growing and immediately starts to curve upwards and forms the characteristic " posthorn ", " bayonet ", " dutch pipe ", or "cupid's bow " type of damage. (Plate VII, fig. 1.) If the break occurs at an early stage of the shoot's development, and if bending is slight, growth is generally sufficient to bring its apex into the centre line again in a few weeks' time; but, if it occurs when growth has nearly ceased, so little headway is made during the remainder of the season that another, and occasionally two more, years' growth may be necessary to accomplish this in opposition to the side branches which attempt to take its place. No case has been noticed in which three years or more have been required for recovery, but it is extremely rare for a leading shoot, deformed in this way into a " tortrix curve ", to live and grow and yet not re-establish itself in the leading position over the centre of gravity of the tree, and become the future main stem. (Plate IV, fig. 3.)

Occasionally, especially in shoots that have fallen through a wide angle, vigour is insufficient to enable them to regain their dominance. These almost invariably die of suffocation, accelerated by rubbing, and natural pruning takes place in a few years' time. Such cases automatically revert to the type of damage described under (*b*). Forking, to a greater or less degree, is also a common complication as a result of this type of damage. This " posthorn " damage is the most serious of all, and unfortunately one of the most common. The tree rarely grows out of the deformation, as may happen with many of the types previously described. It remains permanently disfigured, and not only is the timber greatly depreciated in value but the bend is a source of mechanical weakness to the tree itself and is a point at which windbreak frequently occurs.

(*e*) The leading shoot may be unattacked, but several lateral shoots on one side of the whorl may be killed, while those on the other side remain healthy. This results in the leader being pushed slightly towards the attacked side of the whorl, and in extreme cases forking may occur. This type of damage is comparatively rare and unimportant.

Each of these types of damage may occur to other buds and shoots than those of the apical whorl, but, as they do not affect the future timber, they are only of importance inasmuch as they influence the physiological state of the tree.

Almost as important as knowing what deformations are caused by the insect is knowing what deformations are not. There would appear to be a prevalent idea that all bends found on pine stems are caused by the insect. One fact which emerges quite plainly from the above description of the types of structural damage is that with the exception of that concurrent with the psuedo witch's broom the bends are mostly confined to one year's growth. Even where forking occurs this is usually still obvious. In the case of the posthorn type it often happens that the bends affects two years' growth before the trunk regains its vertical position, but cases where three years' growth are affected are extremely rare. (Two were noted against 1,500 other tortrix bends, on Compt. 3, Swaffham.) No specimen has been recorded which shows the deformation extending over four or more years. The author has, however, seen one specimen exhibited as tortrix work, which contained at least five years' growth in one gigantic curve. It was obtained from one of the belts of gnarled and twisted pine trees which are so common at Brandon, and which are peculiar in that their trunks, up to a height of 6–10 feet are fantastically forked and twisted, while above this height they are comparatively straight. It is certain that these belts were pine hedges which, while young, had been subjected to repeated clipping until the leading branches must have been killed, and that later on, but still many years ago, this practice was discontinued and they were allowed to grow on as best they could. The resulting growth from the lateral branches faintly resembles, but is easily distinguished from, that of tortrix, and it is unlikely that more than a very small percentage, if any, of the deformed trunks is due to the attacks of the insect.

Many other malformations due to squirrels, perching birds, gunshot wounds, windbreak and rubbing, are also likely to be mistaken for the work of tortrix.

Moreover one finds in the case of narrow belts and uneven-aged woods uneven growth which is not a result of tortrix, but is due to an uneven distribution of light. Other insects cause similar damage to that of *E. buoliana*. Other factors, also peculiar to the trees themselves, may cause gnarled trunks, which may wrongly be ascribed to the insect's agency. The leading shoot of a Scots pine never retains the dominance which is exhibited by a larch or a spruce. Invariably, as it approaches maturity, the crown of a Scots pine tends to open out, and this is usually forecast by a forking and gnarling of the crown. On the poor soils of parts of East Anglia this tends to happen at an early age, and typical examples of it can be seen in most of the belts of old trees. The continuation in the following spring of excessive mid-summer secondary growth in the lateral shoots of the leading whorl sometimes inhibits the growth of the central bud. Several examples of this have been seen which resemble damage of the type (*b*).

In the case of bends made several years previously, it is not possible to be certain that these have been produced by *E. buoliana*, as no one definite characteristic is always present. If it cannot be proved, however, that these bends have not been produced by the caterpillar's attack, it is assumed that, as the insect outnumbers by probably over 100 to 1 all other sources of this type of injury, any other cause can be ignored.

FACTORS AFFECTING THE ECONOMIC DAMAGE

These can be discussed under two groups, (A) Factors affecting the population of caterpillars and (B) relations between the host plants and the pest.

(A) Factors affecting the Population of Caterpillars

These may be subdivided into two, namely, vitality and mortality factors.

(1) *Vitality Factors*

(*a*) The first point of importance concerns the manner of introduction of the pest to the area. This may be brought about by the natural flight of moths to the area, by wind transmission, or by the planting in new areas, of young trees which already contain in their buds hibernating caterpillars.

In pine-growing districts in East Anglia and the south of England, caterpillars were found sparsely distributed on mature pine trees. At Fincham, Norfolk, seven miles from any young plantation, 17 caterpillars were taken from 37 felled trees; while in Quorn woods, Leicestershire, and near Goring, Bucks, 2 caterpillars from 5 trees, and 2 from 3 trees, respectively, were taken. In the last two cases there were no young plantations in the vicinity. These figures would appear to represent the normal distribution of the pest from which young plantations receive their initial stock. In Norfolk and Suffolk, all plantations showed signs of infection during the first season after planting, and in one particular case (Compartment 51, Swaffham), infection proceeded from a pine hedge which bounded one side of the plantation. The pine belts and hedges, which are such a feature of the landscape in Norfolk and Suffolk, form the chief sources from which the pest has been distributed over this wide area.

Nothing is known regarding the actual distance to which the moths can be dispersed by wind. Three newly hatched caterpillars were found on some very young pines, 1,600 yards from the nearest source of infection. This migration, however, must have been made against the direction of the prevailing wind and it is possible that the moth came from a heavily infested plantation two and a half miles to windward. As regards the spreading of the pest by the planting of infected plants no data are available for the East Anglian areas.

(*b*) The second point of importance concerns the increase of the insect once it has been introduced into the area. On purely theoretical grounds it can be shown that, provided external factors do not come into play, for every female originally introduced, the offspring which in the first generation is 76, rises by the fourth generation to the enormous total of 3,464,376. Further, it can be shown that if a certain number of moths can leave sufficient progeny to populate an area completely in four generations, 36 times that number will be required to accomplish this in three generations, and 1,280 times the number to accomplish this in two generations. Later additions to the original population are thus of slight significance as 35 times the number of moths originally introduced would have to be added to the first generation, to produce an advance by one year of all following generations, and over 400 times that number to subsequent generations to produce the same effect. In practice, these figures do not work out in this manner as the number of moths which actually survive is always less than the number calculated.

(2) *Mortality Factors*

Adults:—The mortality of the adults before egg-laying is largely due to predators. Moths were often found tangled up in spiders' webs and their remains in the stomachs of long-eared and short-eared bats.

Eggs:—Non-fertilisation and the action of insect parasites account for something like 8 per cent. of the total number of eggs laid.

Caterpillars:—The mortality among caterpillars can be studied before and after their establishment in the buds. Before establishment predators play an important part, ants and other insects preying upon the caterpillars. In this connection the action of heavy rains is interesting: in 1928 heavy rain fell during the hatching period and the mortality of the young caterpillars was 16·8 per cent. of the total number hatched. In the following year this period was dry and the figure fell to 10 per cent. The action of heavy rain and strong winds is probably mechanical, sweeping the young caterpillars off the trees on to the ground where they fall an easy victim to predatory enemies. These two factors operate not only before the caterpillars settle down in the first bud but also later when they migrate from one bud to another.

Once established in the well-protected shelter of the buds climatic factors have little effect. This is seen in the extremely wide geographical distribution of the species which ranges from regions which are sub-arctic to those which are sub-tropical. The protective habitat also shelters the caterpillar from the attack of birds which play practically no part in their control. Collinge, it is true, recorded, in 1915, the finding of some caterpillars in the stomachs of woodpeckers but this record is unique and the caterpillars in question were probably caught during migration. Fungal, bacterial, or virus, diseases likewise exercise no appreciable control over the numbers of the caterpillars. This is probably due partly to the density of the web which the caterpillars spin about their burrows and partly to the antiseptic properties of the surrounding resin. The action of insect parasites is important but of such complexity as to warrant discussion under a separate heading in this Bulletin.

Pupae:—Climatic factors, especially sudden changes of temperature and cold wet weather, appeared to account for most of the pupal mortality observed.

(B) Relations between the Host Plants and the Pest

(1) *Factors affecting Oviposition*

In the description of the life-history given above it has been noted that the eggs are almost invariably laid upon the green bark of the young shoots which suggests that the odour from the bark provides some stimulus to oviposition. Correlated with this, the relative prominence of the trees in the plantation has also to be taken into account, as it is obvious that the more prominent trees will be more readily encountered. It is notable, however, that there is a lower limit of size of twig upon which moths will lay eggs, and this probably explains why the number of eggs laid on the small twigs in the crowns of tall trees is smaller than one would expect having regard to their relative prominence.

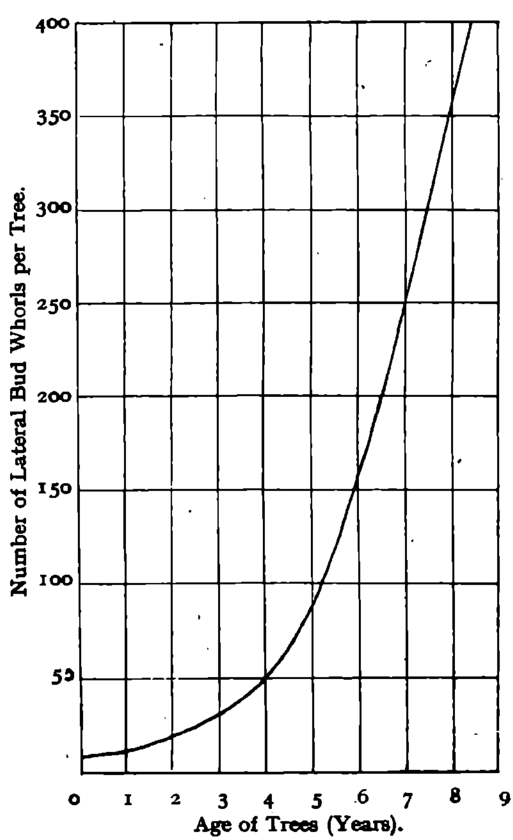
Some data bearing upon these questions have been collected, but they are not sufficient to merit serious discussion. On brief example may, however, prove of interest. It refers to a comparison made between two adjacent plantations differing in age and height. One hundred trees were selected in each, and the total area of the young shoots, exclusive of those under 1·5mm. diameter, calculated. The areas of these shoots were respectively 15,900 and 6,740 sq. inches. The respective populations of eggs were:—1,155 and 512, or 1 egg per 13·2 sq. inches in the younger plantation, and 1 egg per 13·6 sq. inches in the older plantation. This result indicated that in two plantations the populations varied in direct proportion to the area of attractive green bark.

One other factor influencing oviposition is the arrangement of the needles on the shoot. In order to reach the bark, the moth has to penetrate between the needles and in various races and species of pine the arrangement of the needles varies from the type in which they point straight out almost at right angles to the shoot, to that in which they are curved and interlacing in a plane parallel to the bark surface, thus forming a slightly resisting barrier. The Corsican pine has needles of the latter type and this factor has possibly something to do with the fact that it is noticeably less attacked than the Scots pine.

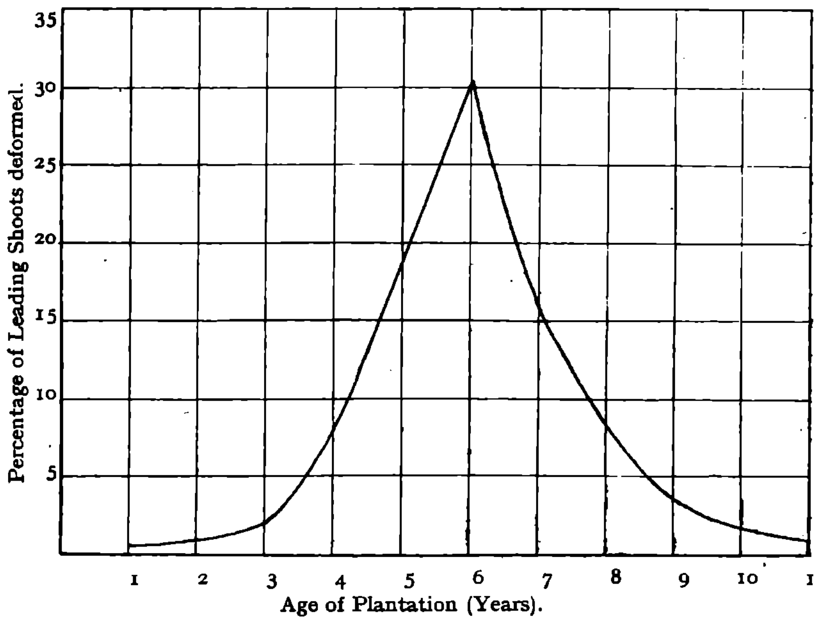
Planting distance also has a marked effect upon the total population of the pest, and in mixed plantations the density of attack is markedly less than in pure plantations. The reasons for this are somewhat obscure.

(2) *Factors affecting actual Damage to the Trees*

From the previous description of the types of damage caused by the pest, it is evident that the most important economic damage is done by the caterpillars which attack the leading bud or shoot. It is also evident that as the tree grows older there is a rapid decrease in the relative numerical proportion of leading shoots to lateral shoots and in consequence the chances of a leading shoot becoming attacked are diminished. The graph below demonstrates the relative proportions of the number of bud whorls on lateral shoots as compared with the leading shoot on trees of various ages. From this graph we see that whereas in a tree, 3 years old, the proportion is as 30 to 1, by the time the tree attains the age of 8 years, this proportion has reached the figure of 350 to 1.



Another important factor relating to damage is the size of the buds themselves. As the young trees grow, the buds increase in size, especially those of the leading shoot. This increase in size affects the amount of migration which the caterpillars undertake once they have settled down in a bud, for the sufficient reason that the larger buds provide all the necessary food. The following graph shows that most of the trees are deformed in the leader during a short, early period, the peak of which is reached about the age of 6 years.



In one plantation at Swaffham four times as much damage was done in 1928 to a 4-year-old plantation, as was done to the same plantation two years later, by nearly five times as many caterpillars. Further, there were indications that in the following year the damage would be even less, although the population was still rising.

The action of these factors is retarded or accelerated by the state of health of the trees. This is directly dependent upon the quality of the plants, soil conditions, and climate. As regards climate, extremes (especially hard winter frosts and summer drought) appear to increase the economic damage.

CONTROL MEASURES

1. Insect Parasites

This portion of the work was left by Mr. Brooks in such an unfinished state that only a brief summary of some of his chief observations is possible.

At the outset it should be stated that the insect parasites of the pine shoot moth were studied some years ago at the Parasite Laboratory of the Imperial Institute of Entomology, Farnham Royal, Bucks. The results were dealt with by Dr. W. H. Thorpe in a paper published in the Bulletin of Entomological Research in 1930. The investigation made by the Parasite Laboratory into the parasites of the moth had as its immediate object the collection of numbers of the most important parasites for introduction into certain parts of Eastern Canada where the pine shoot moth has become established as a pest. The bulk of the material came from the Forestry Commission's plantations in East Anglia. The investigation, which was made upon a very large amount of material, yielded 28 species of primary and secondary parasites. Of these, the dominant species appeared to be, a Braconid, *Orgilus obscurator,* and two Orphionine Ichneumonids, *Cremastus interruptor* and *Omorgus mutabilis*. These parasites were forwarded to Canada and it appears that the first two have since become established there.

Mr. Brooks appears to have reached the same conclusions regarding the most important members of the parasite complex. He records the three parasites above mentioned, but adds a fourth, also an Ophionine Ichneumonid, *Eulimneria rufifemur*.

Eulimneria was found to be a very efficient parasite. It is well represented even in the localities where the host insect is scarce, and one has only to watch the diligent way in which it seeks out every nook and crevice in search of its host to realise its potential utility as a natural enemy. The dates of its oviposition and other details also correspond exactly with the period during which the caterpillars are most vulnerable and it is highly adapted to its life of parasitism within the host. *Cremastus,* on the other hand, is a sluggish parasite and does not occur in numbers except in places where the population of caterpillars is dense. Its periods of activity do not correspond so closely with those during which the caterpillars are vulnerable and, all things considered, it is a less efficient parasite than *Eulimneria*. It holds, however, one advantage over the latter, in that its larva matures more rapidly within the body of the host, so that when a caterpillar is parasitised by both species it is almost invariably *Cremastus* which emerges. This is unfortunate, as it results in the almost complete extermination of the more effective parasite over large areas of even-aged plantations. In plantations of uneven age where belts of older trees exist, the *Eulimneria* breed much better than *Cremastus,* and are able to hold their own and it is from such situations that they should be collected.

In open, six-year-old plantations, *Cremastus* may outnumber *Eulimneria* by three to one. When, however, such plantations are surrounded by, or close to, old belts in which the latter breed better, the proportion between the two parasites is kept roughly constant by immigration into the plantation from the belts. In these cases, the total percentage of parasitism may reach 80 to 85 per cent. Neither parasite however, appears capable, even under the most favourable circumstances, of exceeding 66 per cent. As already mentioned pine shelter belts are frequently responsible for an immigration of moths into the plantations and this is not compensated for by the parasites which they yield. It is interesting to note, however, that the greatest percentage of parasitism is found near these belts.

It has been found that the parasites under discussion have a particular preference for certain levels in the plantations, above or below which they become less abundant and less efficient. The behaviour of the parasite *Omorgus mutabilis* in the Forest of Dean provides an example of this. The pine plantation in which this parasite occurs is surrounded by mature oak forest which is heavily attacked by the green oak roller moth (*Tortrix viridana*), and the winter moths (*Cheimatobia brumata* and *Hybernia defoliaria*). The caterpillars of the winter moths are attacked during their short feeding period by the spring generation of *Omorgus,* the adults of which can find few other caterpillars in the crowns of the trees in which they can lay their eggs. As a result of this, the parasites are driven down to lower levels and attack the caterpillars of *E. buoliana* in the young pine plantations.

When this generation emerges, the majority of the parasites prefer to return to the higher foliage levels of the oak and attack the caterpillars there, so that only a few are left to parasitise the later stages of *E. buoliana*. This preference for the higher levels of the tree crowns is also a feature of this parasite in Norfolk.

From observations made it is believed that while the three parasites mentioned can effect little reduction in the numbers of the pest there is no doubt that they do exert a restraining influence and prevent to some extent the further distribution of the pest.

The possibility of increasing the effectiveness of the parasites' work by artificial means has often been discussed. In the present state of our knowledge it appears that artificial breeding measures would have to be undertaken on such a vast scale that it is doubtful whether the great labour and expense involved would justify the cost of the operation.

2. Artificial Control

It has now been established that after hatching and until the end of hibernation in the spring, the small caterpillars are invariably found in the lateral buds of the large whorls of the leading shoots, except where the plants are so small or of such a poor quality that there has been insufficient food in these side buds, and migration to the leader has taken place—cases which are comparatively rare. This fact at once suggests a method of control. As it is easy to distinguish the whorl affected, by the resinous web which the caterpillar spins between the buds, all that appears to be necessary is to remove the side buds of the whorls on leading shoots which show this web. This will leave the centre bud of the whorl, the future leader, free from attack.

This disbudding operation should be carried out some time during the autumn, preferably about the beginning of October. The work can be done by boys, and is infinitely cheaper and more reliable than the old method of total handpicking, which on many areas is quite impossible.

Several experimental plots have been treated at Brandon and they have all given satisfactory results.

Complete success cannot, however, be claimed, as it has been found that the caterpillars as well as migrating from bud to bud, can also travel from branch to branch and establish themselves in other bud whorls. It is natural therefore that, as the caterpillars work upwards rather than downwards, several of these disbudded leaders and shoots that were not attacked in the autumn, should be attacked again in the spring; this, however, only occurs to a limited extent. The centre bud of a disbudded whorl as it grows in the following season shows a marked tendency towards secondary midsummer growth. This is often harmful to the leader, which may occasionally be smothered by the overgrowth of the lateral buds, but in spite of these drawbacks it is believed that this method of control may be found effective and should be given a trial.

PART 2

THE STATUS OF THE PEST IN EAST ANGLIA AND EXPERIMENTS IN CONTROL

Subsequent to the death of Mr. C. C. Brooks in 1930, Mr. J. M. B. Brown extended the study of the pine shoot moth in two directions: (*a*) to determine the status of the pest in Norfolk and Suffolk, and (*b*) to test the methods of control which had been recommended. The results of this study are set forth in the following pages. Although the experiments in controlling the pest do not justify the hopes originally entertained, the results are set down in the hope that they may be a guide to foresters who have to deal with the pest. The work is based upon numerous field records in the making of which Dr. R. N. Chrystal often participated in addition to offering much useful criticism.

STATUS OF THE PEST IN EAST ANGLIA IN 1933

The extensive areas of land acquired since 1919 by the Forestry Commission have been largely planted with pines. By the summer of 1933, these plantations covered an area of about 21,000 acres in Thetford Chase, 4,000 acres in Swaffham Forest, and 5,500 acres at Rendlesham and Tunstall. Scots pine forms the bulk of the crop, but considerable areas of Corsican pine occur and maritime pine has been locally sown or planted in smaller areas. Between September, 1932, and October, 1933, all the important Scots pine plantations in the three Forests were visited in order that the severity of infestation by *E. buoliana* might be determined. Areas planted since 1928 were usually excluded, because in them the moth had not had sufficient time to multiply. The survey embraced the inspection of over 160,000 trees in 220 Compartments, representing an area of some 13,000 acres of young Scots pine. In addition, certain plantations of Corsican pine of various ages were inspected, in order that they might be compared with the Scots pine as regards susceptibility to damage, and to investigate the reasons for the noticeable immunity of this species.

Two systems were employed in the making of the records. In younger plantations, where the attack was developing, the trees were divided very simply into three classes:—

1. trees undamaged, and with an uninfected leading bud whorl;
2. trees undamaged, but with an infected leading bud whorl;
3. trees already damaged in the leader.

In plantations of this age, the outbreak had not reached its climax and recovery of the trees had not begun, it was therefore considered to be too early to attempt an assessment of the total damage inflicted. The above method, however, allowed for the review of a very considerable area within a relatively short space of time and no large area, within these limits of age, escaped inspection. In each Compartment visited, two to four rows of trees were examined. The results were expected to provide an answer to some of the following questions.

1. Is the moth generally prevalent and abundant, or do large areas escape severe attack? 2. Does the intensity of the attack differ much between plantations of the same age in different areas, or is it rather uniform? What factors control such differences as may be observed? 3. At what rate does the attack increase and spread and when does it attain its maximum intensity?

For the older plantations, a different method was adopted. In these it was impossible to use the simple form of classification outlined above, partly because of the height and density of the plantations, and partly because of the varying types of deformation encountered. Further, it was desirable that the total damage should be assessed in selected plantations which had outgrown the critical period, and that the proportion and distribution of slightly and seriously distorted trees should be determined, as well as the rapidity and degree of their recovery. For these purposes, plots, mostly a quarter of an acre in area, but in some Compartments narrow strips, were cleaned in certain representative portions of severely attacked areas and the trees in these plots or strips were so classified as to furnish the necessary information. Such plots or strips have been inspected in P.22 (rarely P.21 or P.23) areas at Swaffham, Wangford, Rendlesham and Tunstall. These will be re-examined in a few years' time, so that the course of their recovery from pine shoot moth injury may be followed.

Among areas of intermediate age relatively few Compartments were visited. Generally speaking, these were not yet ripe for an assessment of the total damage, yet the trees were too tall to permit of the rapid inspection which was carried out in the younger plantations. In order, however, that a complete series of records should be available, certain suitable plantations of these ages (P.23, P.24 and P25) were included in the survey.

The survey has clearly shown that in the three Forests the moth is, or has been, widespread and abundant. In nearly all the younger plantations the attack, if not already severe, justifies the expectation of serious damage in the near future. In those plantations over ten years old, although the outbreak has quite or almost subsided, the moth has caused considerable damage. There are, however, a few plantations of intermediate age (P.25, P.26) which appear to have escaped lightly and in so far as they were ascertained, the reasons for their comparative immunity will be considered later. It is too early to determine whether certain of the younger plantations where attack is below average will escape to the same extent.

In the younger plantations the intensity of attack, measured as the proportion of infected leaders, was fairly uniform over contemporary plantings in different areas; nevertheless there were factors, other than the age of the plantation, which affected the population of moths.

The following table illustrates the condition of the Scots pine plantations aged 6 and 7 years respectively at the date of the survey.

Locality.	6-yr.-old Plantations.				7-yr.-old Plantations.			
	Approx. Acreage.	O.	T.	X.	Approx. Acreage.	O.	T.	X.
		per cent.	per cent.	per cent.		per cent.	per cent.	per cent.
Swaffham	300	84·6	8·7	6·7	800	60·2	16·5	23·3
Foulden	200	77·1	11·2	11·7	400	18·6	26·5	54·8
Methwold	900	37·6	41·3	21·1	—	—	—	—
Downham ..	1100	61·8	20·8	17·4	800	38·8	25·4	35·8
Lynford	800	62·5	25·5	12·0	400	40·4	33·6	26·6
Elveden	200	60·0	22·7	17·3	600	32·4	32·3	35·3
Rendlesham ..	250	73·6	10·7	15·6	—	—	—	—
Average	3750	59·5	24·5	15·8	3000	40·75	25·65	33·6

O = Percentage of trees with sound, uninfected leaders.
T = ,, ,, ,, undamaged, but with buds of leading shoot attacked.
X = ,, ,, ,, whose leading shoot had already been damaged.

The outbreak develops more rapidly where the trees grow quickly clear of the surrounding vegetation. Where the trees are backward, or, as is often the case, where they have to make their way through a strong growth of bracken, the moth population takes longer to reach its peak. A good instance of the operation of this factor was observed at Beechamwell, Swaffham Forest. On one area of P.26, growing rapidly on grassland, the outbreak had already passed its maximum in March, 1933. In an adjoining area of the same age where the trees were growing much more slowly amid rough vegetation the attack was still quite recent. Data obtained from the older areas showed, however, that this factor did not reduce the maximum population of moths in these slower-growing plantations below that of the others. Another factor which sometimes affects the moth population is the ease with which the plantation becomes infected. It is probable that the chief source of infection of young plantations is provided by the belts and hedges of Scots pine aided by the older, infested plantations. Few young plantations are sufficiently remote from at least one of these sources to escape infection for more than a year or two. Plantations with infected, older trees directly to windward will develop the attack more rapidly, as will also those which are formed with infected nursery stock. It was frequently observed that the proportion of infected leaders in that part of a plantation immediately adjacent to older pines was considerably higher than in those parts remote from this source of infection. At the same time, despite the fact that the moths do not travel rapidly or far afield, attack spreads slowly but surely over the entire area. Typically, unless already infected from the nursery, plantations become infected during their first season of growth. The moths multiply in a few centres in the plantation, slowly at first, and then, as they increase in numbers, spread over the whole area. The pest becomes noticeable in the fifth season after planting, when 10–20 per cent. of the leaders may be injured. Substantial damage is inflicted in the following season, the percentage of injured leaders rising to between 30 and 50, and by the end of the eighth season only a small proportion of leaders remains uninjured. In the ninth season, the attack may abate; but damage may still be inflicted on some of the remaining uninjured leaders for a further two years, as well as on some of those which have recovered from earlier injury. The outbreak develops more rapidly in some plantations than in others, while in the exceptional areas already referred to above, it culminated at a much lower intensity. In the younger areas the outbreak appears to be progressing more slowly than was the case in the older ones. The following table summarises the information collected in selected older areas:—

—	P.22. Swaffham.		P.22. Wangford.
	Compt. 1.	Compt. 4.	Compt. 6.
	per cent.	per cent.	per cent.
Trees first damaged in 1925	6·6	9·3	8·5
Trees first damaged in 1926	18·8	24·2	8·3
Trees first damaged in 1927	29·0	27·0	13·9
Trees first damaged in 1928	13·9	16·0	14·1
Trees first damaged in 1929	2·6	7·3	13·9
Trees first damaged in 1930	5·4	3·0	10·7
Trees first damaged in 1931	0·7	0·9	2·8
Trees first damaged in 1932	0·5	0·5	1·2
Trees apparently never damaged (March, 1933)	22·5	11·8	26·6

—	P.22. Swaffham.		P.22. Wangford.
	Compt. 1.	Compt. 4.	Compt. 6.
	per cent.	per cent.	per cent.
Trees never damaged in leader	22·5	11·8	26·6
Trees once damaged in leader	33·0	30·2	40·2
Trees twice damaged in leader	28·7	33·7	24·8
Trees thrice damaged in leader..	10·6	17·7	6·4
Trees four times damaged in leader	3·8	5·5	2·0
Trees five times damaged in leader	0·94	1·1	0·2
Total number of leader injuries	609	823	597
Total number of trees	425	463	507
Average number of injuries per tree	1·41	1·78	1·18

It must not be assumed that, because over most of the area the course of attack is uniform, the degree of permanent injury inflicted is equally so. This is dependent upon important factors other than the density of the moth population. Sturdy trees with large buds withstand leader damage much better than weakly trees with small whorls of buds. On one of the former two or three caterpillars might find enough nourishment in the side buds alone, whereas a single caterpillar might devour the entire leading whorl in the latter case. Other things being equal, the proportion of leaders which escape damage is appreciably higher in healthy, as compared with backward, plantations.

The density of planting is another factor which may influence the amount of deformation. Its manner of operation is discussed in the section on control but, owing to the similarity of the spacing of the pines, the actual distribution of severely injured plantations is not at all referable to this factor. On the other hand, the tree's growth in the few years after the climax of the outbreak is a critical factor. Where this growth has been rapid and even, not seriously checked by continuation of tortrix attack, or by infestation by the aphid, *Lachnus pini,* recovery has been good. Trees have competed one with another for light, fresh leaders were soon gained by the majority of the damaged trees, and the commoner, milder deformations have been almost obliterated. Where growth has been slow, or hampered by *Lachnus* attack, that stimulus to height growth has been absent and recovery of damaged trees delayed and imperfect. Generally speaking, it is in those plantations where poor growth has aggravated the attack that sustained poor growth has impeded recovery.

The sample plots and strips in the older plantations in each of the principal areas have demonstrated how serious the attack has been, and how the trees are recovering from it. The original intention was to classify the trees in these plots primarily as: (1) suppressed or dead trees; (2) dominants—unattacked or only slightly distorted; and (3) dominants—seriously distorted. On account, however, of the immature state of the stands, it was impossible to segregate, on the one hand, all trees in process of suppression, or on the other, all those permanently deformed. Consequently, the following method of classification was finally adopted:—

1. dominants, quite undamaged by the moth;
2. dominants, which have recovered from slight deformation;
3. dominants, with moderate deformation, or whose recovery is doubtful;
4. small trees in danger of suppression, but undamaged;
5. small trees in danger of suppression, slightly damaged;

6. suppressed trees;
7. trees with serious, apparently permanent, deformation;
8. dead trees and gaps.

Roughly speaking, Classes 1 and 2 represent good trees; 3, 4, and 5 may, in a certain porportion of cases, form large trees without serious blemishes; but little is to be expected from those in Classes 6 and 7.

The results of this examination are summarised below.

Class of Tree.	Swaffham.		Wangford.	Rendlesham.	Tunstall.	Mean.
	P.23.	P.22.	P.22.	P.22.	P.22.	P.22.
	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.
1	12·9	9·2	13·5	5·8	5·8	8·3
2	25·4	29·6	25·4	25·0	15·2	23·8
3	13·5	10·7	10·2	12·1	12·5	11·4
4	2·9	2·8	9·3	1·3	1·0	3·6
5	8·0	9·4	12·3	9·3	6·4	9·4
6	4·0	9·3	8·3	8·3	5·3	7·8
7	30·7	26·8	20·0	30·0	51·7	32·1
8	3·1	2·2	1·2	8·2	2·0	3·4

This table shows first, that the great majority of the trees had been damaged in the leader. 11·9 per cent. of the original plantation, that is 13·4 per cent. of the survivors, retained no trace of deformation; for the dominants only, this proportion was 11·5 per cent., and for the partially suppressed trees, 21 per cent. Secondly, the table shows important differences between one locality and another. Wangford and Swaffham, with 39 per cent. of good trees and 20–30 per cent. of distorted trees, appear as the best areas. The proportion of distorted trees is appreciably higher at Swaffham than at Wangford, but this is partly compensated by the less sturdy growth in the latter area and by the more promising recovery at Swaffham. At Wangford, the P.22 was less extensively surveyed than at Swaffham, and the figures given here may not present as true a picture of that area. The present state of the Rendlesham plantations is not quite so good, the numbers of straight and distorted trees being approximately equal. But the widest divergence from the mean was found at Tunstall, where two Compartments contained an average of only 21 per cent. of good trees, as against 51·7 per cent. distorted trees. In the worst Compartment, these figures were 16·7 per cent. and 56·4 per cent. respectively.

The distribution of the different kinds of trees is important. Diagrams have been prepared of certain of the plots at Wangford and Swaffham. Rather uniform on the whole, the distribution shows some patches of distorted and suppressed trees; dominants of good shape are well enough distributed to furnish a considerable crop of large timber, but there are places where the removal of the distorted stems in the thinnings would leave openings in the plantation. Some of these gaps might be satisfactorily filled by trees of Class 3, whose malformations become obliterated as they increase in size; others may be filled by the smaller trees in Classes 4 and 5, if timely thinning releases them before they become suppressed. As noted above, the proportion of distorted stems is rather higher among the dominants than among these smaller trees and instances of badly distorted trees dominating good trees are not infrequent. The foresters propose trying whether the best of these can be set free to form good trees, by early removal or lopping of the trees which threaten to suppress them. The older plantations at Rendlesham and Tunstall have not been surveyed from this point of view. While it is probable that a diagram of the Compartments visited at Rendlesham would not differ very much in general appearance from those prepared from the Swaffham data, it is certain that Tunstall would appear in a much less favourable light. That these plantations will yield a crop of good timber is unlikely; something may be done to promote the growth of the straight trees, but many of the distorted must be left to keep the canopy intact. No doubt the Compartments differ in the amount of damage which they have suffered, but the figures given are probably not far from the Tunstall average.

The ugly appearance of the Tunstall area may be due partly to a heavier infestation by the moth, but chiefly to poor growth and recovery. The contribution of the first cause cannot now be assessed; the importance of the second is undeniable. The health of a pine is reflected in the size of its buds; when these are small, more of them are required as food by a given number of caterpillars, whose capacity for inflicting injury on the leaders is thus enhanced. From this injury, moreover, weakly trees do not recover so readily as healthy ones; the latter form a thicket more rapidly and, competing for light, aid one another to regain straight leaders. This stimulus is lacking in slow-growing, open plantations, where injured trees have greater licence to develop wide curves or permanent forks,

The question may be asked: what kind of trees are included in Classes 2 (insignificantly damaged), 7 (badly damaged), and 3. Class 2 includes all those numerous trees which have evidently had the leading bud or shoot killed in one season at least; but recovery has been early and good, and a slight bend is the only trace left at the point of damage. This usually diminishes as the tree increases in size, and in some cases may be quite obscured when the next assessment is made. It is hoped that these trees will furnish timber of as good a grade as that from uninjured trees, but it would be interesting to have specimens technically examined at different ages. In most of the plantations under review, such trees will certainly predominate in the crop. Most of the trees in Class 7 are either those showing the characteristic posthorn, or forked trees. The origin of the former type of injury has been fully discussed by Brooks; it results in a well-marked curve, 2–8 inches in amplitude, and from 6–20 inches long (Plate VII, fig. 1). The malformation is permanent and restricts the use to which the whole stem can be put, but if the crook is low down—as it frequently is—a good length of straight timber may later be available above it for service as a telegraph standard, or to be cut into lengths for railway sleepers. Thus many of these trees may ultimately form timber of some value.

Forked trees may have two or more stems competing for leadership. Those with two leaders are occasionally formed when the leading shoot is killed and two surviving side shoots grow up equally in its place. Some of these trees may yet recover well, if one of these leaders suppresses the other; those that do not do this are incapable of producing large timber of good quality. Trees with multiple leaders are commonly produced when the entire leading whorl of buds is destroyed and replaced by adventitious buds with restricted powers of growth (Plate IV, fig. 1); the side shoots of the first whorl grow up around the injured leader. One of these may sooner or later form a fresh leader, but at the cost of a considerable bend; or, alternatively, three or more of them may develop equally and form a spreading, shrubby tree, from which no good may be expected. Class 3 comprises, on the one hand, trees whose malformation, although sufficient to justify their exclusion from the good trees, is not serious enough to justify their inclusion with the bad. Class 3 also comprises trees which have recently been damaged, but which have not yet sorted themselves out as good or bad. Later inspection will, of course, result in a certain amount of rearrangement of the trees in the classification. Although the outbreak is almost at an end, a few trees, classed originally as 1 or 2, may yet be injured and require to be degraded; whereas some of Class 3, and perhaps also of Class 7, may recover so well that their inclusion with the good trees is warranted. Similarly, some trees classed as dominant may become suppressed, and some which were in danger of suppression may recover. The plots which were laid out during the winter of 1931–1932 were revisited in March, 1934, and indicated the changes that are expected to occur, but the interval was too short for changes of magnitude.

Some of the information which these sample plots may furnish will not be available until nearer the end of the rotation; if they help the forester to estimate the losses for which the insect is liable, to appreciate its dependence upon environmental conditions, and to ascertain how far he can profitably mitigate this damage by silvicultural measures, they will have served their purpose.

The only important result of the survey remaining for discussion is the status of the pest in the plantations of Corsican pine. It was observed everywhere that Corsican pine, even in the neighbourhood of infested plantations of Scots pine, enjoyed a high degree of immunity from injury.

At Olley Farm an experimental plot of Corsican pine adjoining a large area of Scots pine of the same age (P. 27) provided valuable data and the results are set out in the table below.

	Scots Pine.		Corsican Pine.	
	At Sept., 1932.	At Sept., 1933.	At Sept., 1932.	At Sept., 1933.
	per cent.	per cent.	per cent.	per cent.
Normal trees, showing no injury either to the current or to the previous year's leading shoots	60	32	64	53
Trees showing no injury to the earlier leading shoots, but with buds of the current year's shoots attacked ..	23	20	31	37
Trees with the main stem damaged ..	17	48	5	10

It will be seen that while the percentage of normal undamaged trees fell in Scots pine from 60 per cent. in 1932 to 32 per cent. in 1933, in Corsican pine the drop was only from 64 to 53 per cent. The middle row of figures indicates, however, that the incidence of attack in September, 1932, was actually greater in the Corsican pine (31 per cent, as compared with 23).

In another area records were kept of the condition of the leaders of over 600 plants of Corsican pine. The initial position in September, 1932, was that 30 per cent. of the bud whorls of the leading shoots showed evidence of infestation by the caterpillar. At the end of twelve months the proportion of trees with lost leaders was only 8 per cent. These data clearly show that while the moths lay their eggs on Corsican pine just as readily as on Scots pine and the caterpillars develop normally in the autumn, the significant damage, *i.e.*, the loss of the leading shoot, is far less frequent in the case of the Corsican pine. The reasons for this have not been definitely determined, but size of bud is probably one contributing factor, the larger side buds of the Corsican pine provide more food material for the caterpillars which consequently are less likely to require to migrate to the central bud. Another possible factor is the highly resinous character of the buds of Corsican pine. It seems quite conceivable that the resin flow may cause the death of some of the caterpillars, but the discovery of a few dead larvae submerged in resin is the only positive evidence bearing on this matter.

If there is mortality of the caterpillars in the Corsican pine buds the obvious consequence must be a reduction in the population of the pine shoot moth and thus an outbreak might never attain the intensity of which it is capable in a pure plantation of Scots pine. As evidence pointing in this direction it was found that certain of the pure Scots pine plantations which were adjacent to pure Corsican pine, or to mixed plantations of the two species, showed a lighter attack than was expected.

Conclusions.—On the whole the survey has brought two encouraging facts to light, namely, the good recovery of a considerable proportion of the damaged trees once they have grown out of the most susceptible stage, and the relative immunity of Corsican pine. Further it appears that the outbreak is developing more slowly in the young plantations than it did with corresponding crops of five years ago, and we may hope that the amount of injury inflicted will be less in the future than in the immediate past. We cannot expect to find soon a state of biological equilibrium, but it is not unreasonable to conjecture that gradually the interrelations of host tree, pest, and parasite, will so alter that outbreaks will become rarer and less intense. A repetition of the survey in five to ten years' time should be of great interest from this point of view.

CONTROL MEASURES BASED ON MR. BROOKS' RECOMMENDATIONS

The control measures tried in East Anglia were based upon C. C. Brooks' observation that in autumn the caterpillars rarely invade the centre bud of the leading shoot but are commonly lodged in one of the side buds. Only after the resumption of activity in the spring are the leading buds and shoots severely attacked. Brooks suggested, therefore, that if all infected leading whorls were stripped by hand of their lateral buds the centre buds would, in the great majority of cases, be free to sprout unharmed in the spring. Such infected whorls of buds may be recognised without much difficulty by the resinous web which betrays the presence of a caterpillar. Consequently, all that Brooks' measures demanded was for boys or men (according to the height of the trees) to pass up and down the rows and to pick off the side buds from all infected leading bud whorls. The reader will appreciate that eradication of the pest is not the end in view, nor even sensible reduction of numbers, but merely the deflection of its attack from the vital leading shoot upon the growth of which the form of the stem depends.

Experiments designed to test the value of these measures were laid out in Thetford Chase in 1930 and 1931. The operation cost about two shillings per acre—not a large sum—and the work was in most instances done satisfactorily, but the results proved conclusively that, although the operation can be cheaply carried out, it is quite inadequate to protect the young trees from injury. A number of trees with their central leading buds already infected in autumn were the source of some of the unsuccessful operations, but the results suggested that the spring migrations of the caterpillars were the chief cause of the unexpected injury to the leading shoots originally uninfected and to those freed from infection by disbudding. The consequences of attack were examined in more than 2,000 individual trees, distributed between a plot which was disbudded by the author and a corresponding control plot.

It was found that (*a*) only about half of the disbudded infected leaders escaped distortion; (*b*) a large proportion of the infected leaders in the control (nearly 40 per cent.) escaped injury although not operated upon, and (*c*) an appreciable proportion (over 20 per cent.) of leaders, apparently uninfected in autumn, suffered damage notwithstanding. It will be clear from this that the damage inflicted was scarcely less in the disbudded plot than in the control and that the results achieved did not repay even the small expenditure.

A further disbudding experiment in which a more elaborate treatment was concurrently tried, bore out the conclusions drawn from previous experiments, namely, that negligible benefits are conferred by the treatment on a severely infested plantation. The proportion of disbudded leaders which escaped injury was scarcely greater than the proportion of infected leaders in the control which escaped injury through the dissipation of the attack in the side buds. In a lightly attacked plantation, disbudding can confer a measurable advantage, but provides no protection from the subsequent intensified attack.

The reaction of the tree to the operation may now be briefly considered. In the majority of successfully disbudded leaders, the height growth made in the following season exceeds the normal, and this feature, combined with the total lack of side shoots above the second whorl, makes such trees rather conspicuous in a plantation (Plate VI, fig. 2). In a small number of cases, a cluster of adventitious shoots takes the place of the shoots of the first whorl and the length of the leading shoot may then be below the average. It also frequently happens, as Brooks observed, that midsummer shoots break out at the tip of a disbudded leader (Plate VI, fig. 1), and these are sometimes strong enough to impede the growth of the leader in the succeeding season. But these disadvantages, attendant upon unsuccessful operations, are not important, and the more usual effect is a stimulation of the height growth of the tree. It is when disbudding fails in its object, as it too often does, that a more serious disadvantage follows. Several hundred instances of damaged disbudded leaders were examined and it was found that in 87 per cent. of these the leading bud or shoot had been killed; in 12 per cent. the shoot had been gnawed and deformed into the typical posthorn and in 1 per cent. it had been otherwise seriously distorted. A corresponding analysis of the damaged leaders in the control gave again 12 per cent. of posthorns and 2 per cent. additional cases where the leading shoot had been seriously injured, but not killed. In the remaining 86 per cent., the leading bud or shoot was dead, but in only 21 per cent. had the entire uppermost whorl been destroyed.

The prospects of obtaining a straight stem are evidently better in the case of plants which have one or more living shoots surviving from the leading bud whorl, than where all these buds are destroyed and the new leader has to come from one of the lateral branches of the whorl below. All the attacked, disbudded plants come into the latter category, but in the controls which have not been subjected to disbudding only 21 out of 86 per cent. of damaged trees were in the same plight, while in the remaining 60 per cent. some of the shoots from the leading bud whorl survive, giving the plants a reasonable prospect of recovery. For this reason alone disbudding is not to be recommended.

The earlier experiments indicated that the chief cause of failure lay in the spring migrations of the larvae, which brought secondary attack to many disbudded leaders, and to many others uninfected at the date of the operation. In severe outbreaks a considerable proportion of infected centre buds was another disturbing factor. Two modifications of the treatment, designed to overcome these difficulties, were then tried. In the first experiment, the disbudding of the leading shoot was combined with the pruning of the top two whorls of side shoots. It was hoped that this additional operation would, without harming the tree, isolate the leading shoots in some measure from secondary attack in the spring. The results were assessed after the following growing season and proved that the treatment could have no practical application in the control of the pest. Although the pruning certainly reduced the number of migrating caterpillars, those that remained were encouraged by the treatment to attack the leading shoot. Apparently no operation short of the costly removal of all infected shoots can afford the leading shoot immunity from subsequent attack. The percentage of leading buds injured was indeed somewhat higher in the control, but this was more than compensated by their better average recovery. Many of these retained sound side shoots, ready to replace the damaged leader and, in a considerable proportion of cases, this recovery took place within a year of damage.

The second modification demanded the postponement of the operation until the commencement of flushing in the ensuing spring. At this season, infected buds are usually betrayed by their crooked growth. All the infected, but hitherto undeformed, tips were so treated that a single healthy shoot was left on each, this being, of course, the centre shoot where possible. It was hoped that these shoots would remain immune from subsequent injury and that the trees would thus survive the year's attack. At the same time, another plot (Plot 1) was indiscriminately disbudded, the centre bud or shoot being left, regardless of whether it showed signs of infection or not. The results, obtained in October, are here summarised:—

	Per cent.		
	Control.	*Plot* 1.	*Plot* 2.
Proportion of damaged leaders	51	52	45

The selective disbudding of Plot 2 apparently gave it a slight advantage over Plot 1 and over the Control Plot; but the expense of the treatment, multiplied by the number of years in which it would have to be carried out, is quite out of proportion to the small result achieved. It is possible that further postponement of the operation might have enhanced the result by allowing most of the migrating caterpillars to settle first. But such delay would have encouraged larvae in the leading bud whorl to invade buds previously uninfected, because in a severe attack the larvae are often abundant enough to destroy every bud on the whorl.

Conclusions regarding Artificial Control

It is now evident that the autumnal disbudding of leading shoots, as tested in these experiments, can have no practical application in the control of the pest, nor does the additional operation of pruning the upper side branches have any protective effect. Collection and destruction of all pruned shoots might promote this effect, but the cost of the treatment would certainly be out of all proportion to the value of the results achieved. Selective disbudding in spring has given slightly favourable results, which might be enhanced by very careful attention to the date of the operation. But, as explained above, there is little ground for believing that a substantial degree of control is possible by this method, and it is very doubtful whether the work could be entrusted to labourers.

The only other method of mechanical control which has been suggested involves taking the plantation in hand while the outbreak is still young and pruning all the infested shoots with a view to the local extermination of the pest. This has not been tried in East Anglia but gives little promise of favourable results for the following reasons: (*a*) the attack originates in the smallest beginnings; there would be grave danger of its resuscitation from the original source, or from infected shoots which had been overlooked; (*b*) many of the young and still undamaged plantations in East Anglia are adjacent to older, infested areas, whence re-infection might come.

At the same time, there is reason to believe that the younger plantations are more susceptible to leader damage and, perhaps, slower in recovering, than plantations over five feet in height, so that measures which are effective in delaying the initial rise of the outbreak should prove beneficial. Thorough cleaning up of young plantations might be worth while where the danger of re-infection appears to be slight, or where the initial attack can be traced back to the nursery, but if nursery stock be thoroughly inspected this case will not arise.

While direct measures for combating the pest have, so far, proved abortive, there are certain silvicultural measures which, if attended to in so far as may be practicable, would aid the trees' resistance to damage. Scots pine should not be planted extensively in places where it does not thrive in its earliest years. On very poor soils the plants remain small and stunted for many years and the buds are conspicuously small; the chances of larval attacks being confined to some of these side buds and the all-important central buds being spared are much smaller. In strong, healthy trees on good soils the buds are large and, unless attack is very intense, the centre buds of many infected leaders escape invasion. Further, if the buds are large, there is much less likelihood of the entire leading whorl being destroyed or deformed, as often occurs when the buds are undersized; when this happens, the recovery of the tree is greatly retarded. Again, on strongly growing trees, the buds are frequently very resinous and less easily bored by the caterpillar. The health of the tree is, perhaps, still more important in respect of the part it plays in influencing the rapidity of recovery after damage. If circumstances are favourable, the plantation grows rapidly and uniformly in the few years following attack, the trees compete one with another for light and fresh leaders are soon acquired by most of the damaged trees. In this way the slight deformations which are the most frequent result of the attack are often almost obliterated. This condition is well illustrated at Swaffham where after the attack abated in 1929–1930, the trees grew vigorously and a great improvement was soon manifest in most of the plantations. On the other hand, where growth is slow and where the plantation contains many blanks and backward trees, recovery is slower and less satisfactory. At Tunstall, growth in certain of the Compartments is very poor and the great difference between them and the plantations of the same age at Swaffham is by no means entirely due to differences in the severity of the attack. Without doubt, also, care in choosing good plants will, in the same way, promote resistance to damage.

In all the Forestry Commission's East Anglian plantations the trees are spaced 4 feet or 4½ feet apart and have, therefore, furnished no material for direct study of the incidence of attack and recovery in plantations of different density. Since the outbreaks appear to have a definite termination it might be presumed that, in a densely planted area, the number of undeformed trees per acre remaining after attack would be greater than in one sparsely planted. It is possible that closer planting would favour the multiplication of the insect, but trees 4 ft. 6 in. apart already provide such a good breeding ground that the curtailment of this distance would hardly have any effect. Be this as it may, however, there is good reason to believe that closer planting would promote recovery from attack. It would involve, of course, appreciably higher outlay in establishing the plantation, but some of this could be saved in the cost of filling up gaps, and it is possible that this initial expense might be more than offset by a greater ability to withstand the damage wrought by the moth.

The resistance of Corsican pine to attack should be carefully weighed against the advantages, in other respects, of Scots pine. The nature of this resistance has been discussed in a previous section and the best means of exploiting it may be considered here. Within the limits of the demand for the timber, Corsican pine should be grown in preference to Scots pine, particularly on soils where serious damage to the latter by the tortrix may be expected. The rapid growth of Corsican pine and its relative immunity from injury by rabbits and pine aphis (*Lachnus*) should also commend it. There is ground for the suggestion that, when mixed with Corsican pine, Scots pine would suffer less from the depredations of the moth, and the evidence of some small areas in East Anglia supports this view. Unfortunately, the more rapid growth of Corsican pine would generally entail the inevitable suppression of the Scots pine, while the tendency of the former species to remain almost dormant for a year or two after planting would lessen its protective influence. It is, however, certainly to be recommended that, where the planting of an extensive area with Scots pine is contemplated, a wide strip of Corsican pine should intervene between that area and such sources of infection as old pine belts, pine hedges or infested plantations. Friend and West have shown that the moths spread only very slowly, and any measure calculated to check this spread may be advocated but it must be supplemented by a rigid examination of outgoing nursery stock. Finally, Corsican pine should be used for shelter belts and hedges, if these are needed in areas freshly acquired for planting with pine, or, if soil conditions justify their use, hardwoods may replace pines for this purpose.

Recent Investigations in Artificial Control

During 1934 and 1935 experiments have been carried out at Rendlesham in the treatment of plantations of 12 years of age and upwards, in which a serious outbreak of pine shoot moth has subsided. The moths, as Brooks noted, attack most freely the taller trees in a young plantation and instances of badly deformed large trees threatening to suppress smaller straighter trees are not infrequent. The object of the experiments referred to was to find out whether the condition of the plantations can be substantially improved by the removal of the large, coarse trees at this stage so that straighter individuals may be set free to form part of the crop. It is certain that some reduction in the damage can be effected by this treatment, but in plantations which have been severely attacked nothing much can be achieved without a drastic opening of the canopy. It is possible that an equal result could be more easily and more cheaply secured by the removal at an earlier age (say at 8 years) of all posthorn leaders. This treatment, however, would be worth while only where such posthorns are common: in many severely attacked plantations of weak growth posthorns are very scarce.

In this connection, the danger of outbreaks of the pine shoot beetle may be briefly discussed. It is probable that much of the produce of the earliest thinnings will be unsaleable and, if a large population of *Myelophilus piniperda* is allowed to breed in this material, in or near the plantations, the injury already caused by the pine shoot moth will be multiplied. Further, the sooner thinnings are begun, the greater will be the quantity of unsaleable material and the graver the potential injury to the most valuable part of the stem. These dangers are being anticipated and a check is being kept on the population of *Myelophilus* in and near the plantations, while experiments are being planned with three chief objects:—

(i) To ascertain whether thinnings cut in summer are as suitable for breeding as those cut in winter.

(ii) To find out whether beetles breeding in these small poles are adequately controlled by natural agencies.

(iii) To discover the most economical means of disposing of unsaleable thinnings with a view to preventing pine shoot beetle outbreaks.

BIOLOGICAL CONTROL

Extensive lists of hymenopterous parasites of the pine shoot moth have been published, the most detailed list being that by Thorpe, but so far no ecological study of the parasites in East Anglia has been undertaken. Observation shows that the outbreak develops rapidly after the plantation is made and reaches its peak when it is from six to ten years of age. A rapid decline then sets in and, after ten years, the caterpillars are only to be found by searching. The source of this decline has not been traced, but multiplication of parasites is the only factor which seems capable of determining it. In the early years of attack the parasites, hampered as they must be by a difficulty in finding alternate hosts in extensive areas of pure Scots pine, are unable to multiply rapidly enough to keep the host moth in check, and it evades their control. After a number of years, however, the parasites, reinforced perhaps by individuals from adjacent areas, succeed in gaining the ascendancy and equilibrium is quickly restored. It is interesting to speculate whether heavily parasitised material, collected in a plantation where the outbreak was on the wane, and transferred to one in the initial stages, could prevent the outbreak from maturing there. The material might be placed in cages, so constructed as to permit the escape of the parasites while retaining the moths; or, as the most important parasite outlives the moths, the cages might first be opened when the latter were dead. That caged shoots should be placed in the plantation from which they had been taken, has been proposed before; but the present proposal concerns the transference of parasites from areas where they are plentiful to areas threatened by a severe attack and where parasites are scarce. It is unlikely that the measure could have any widespread application; but the conditions in East Anglia, with extensive areas representing every stage of the outbreak, are ideal for an experiment along these lines. First, however, the exact part played by the parasites in eventually bringing outbreaks under control must be determined.

At the same time, a preliminary ecological study of the parasites might indicate in what measure the severe and widespread outbreaks in these Forests may be ascribed to a disturbance in the natural relations between parasites and pest, and whether there are any modifications of treatment which, by favouring the breeding of parasites, might restrict that of the pest. There are good reasons for believing that, whereas the extensive areas of pure pine, which comprise the bulk of the Forestry Commission's woodlands in East Anglia, provide optimum breeding conditions for the pine shoot moth, they are unsuitable to the polyphagous ichneumons, many of which require alternate hosts in the season when larvae of *E. buoliana* are not available. How far these conditions could be remedied it is difficult to say. Plagues of common insects, like other plagues, appear to be a natural phenomenon. By our methods of silviculture we have loaded the scales in favour of the pest but, even if we could find some means of counterbalancing this, it must not be assumed that the net result would be a stable equilibrium. An investigation of this problem would certainly furnish useful information, and the results might have practical value; but only the patient accumulation of facts for three or four years can form the basis of any concrete proposals. Interesting results should be given by the comparative studies of the parasite complex on different kinds of land (*e.g.*, heath and breckland); by the comparison of pine woods in East Anglia, with similar woods elsewhere (*e.g.*, New Forest); and, in particular, by a study of the importance of the parasites in a mixed hardwood-pine association.

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ILLUSTRATIONS

PLATE I

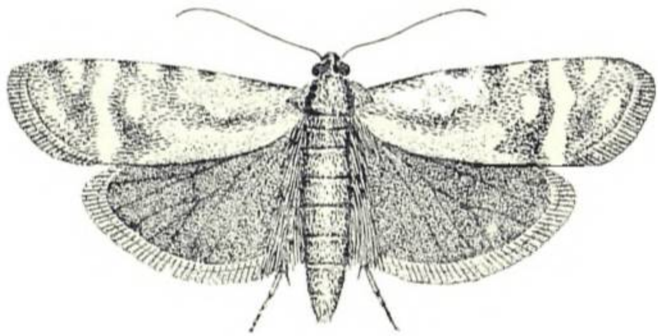


Fig. 1.

Pine Shoot Moth (*Evetria buoliana* Schiff.).
Considerably enlarged.

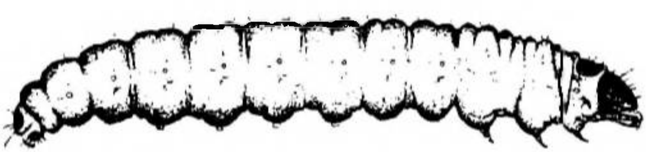


Fig. 2.

Larva (*Evetria buoliana* Schiff.).
Considerably enlarged.

PLATE II.

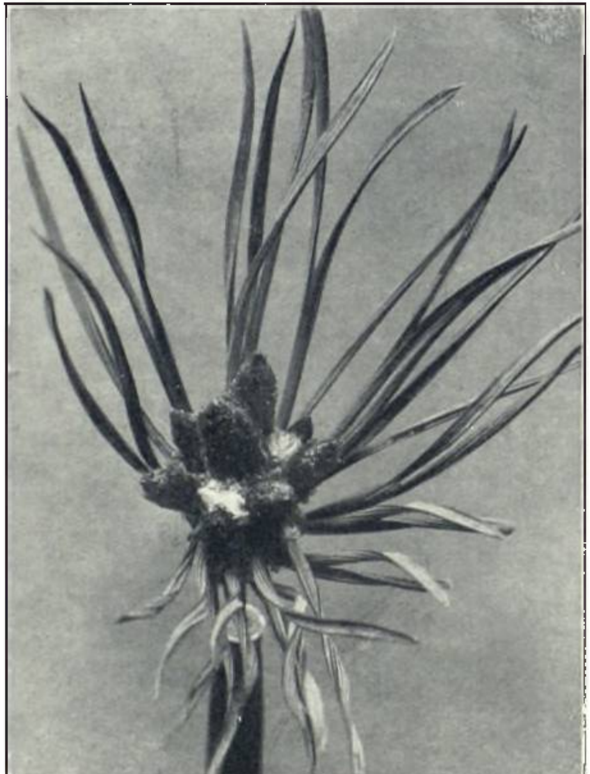
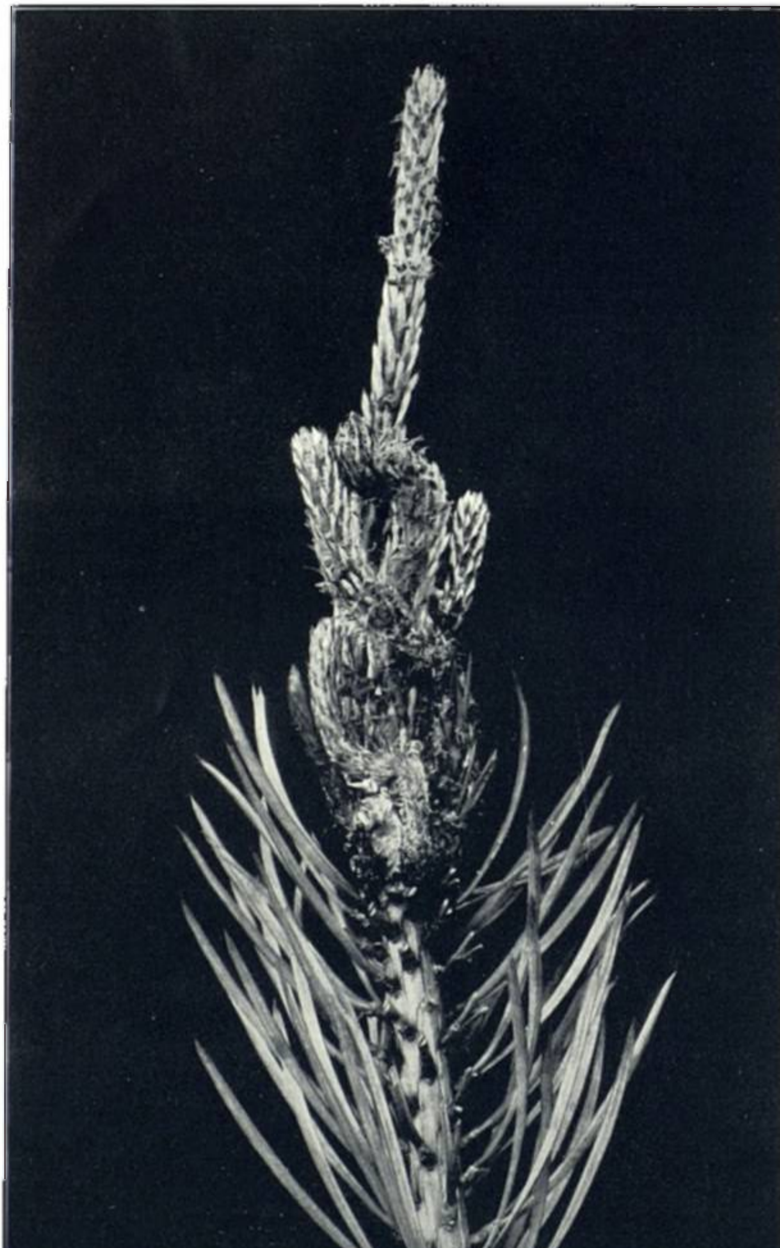


FIG. 1.
Early stage of attack showing resinous web spun by caterpillar between the buds in autumn.

FIG. 2.
Pine shoot cut open to show the caterpillar *in situ*. Note the old tunnel in the dead shoot on the right of the picture

PLATE III.



Developing shoot of Scots pine showing effects of attack by caterpillar.

FIG. 1.
The central bud of the young tree has been destroyed and no leading shoot remains.

FIG. 2.
" Witch's broom " damage.

FIG. 3.
Common type of damage. The leader having been killed, its place has been taken by the strongest side shoot. This has caused a slight deviation of the stem from the perpendicular and incipient forking. This tree shows the result of two attacks.

PLATE V.

(a)

(b)

(c)

Damage to main stem of Scots pine : (a) at 5 ; (b) at 15 ; and (c) at 21 years of age.

PLATE VI.

FIG. 1.
Scots pine disbudded, adventitious shoots developed.

FIG. 2.
Scots pine successfully disbudded two years previously showing no injury in succeeding years.

PLATE VII.

Fig. 1.
"Posthorn" damage to Scots pine unsuccessfully disbudded two years previously.

Fig. 2.
Bushy growth of Scots pine following unsuccessful disbudding two years previously.

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