STUDIES ON THE

SPRUCE BUDWORM

[*Cacoecia fumiferana* Clem.]

PART I

A General Account of the Outbreaks, Injury and Associated Insects

By J. M. Swaine and F. C. Craighead

PART II

General Bionomics and Possibilities of Prevention and Control

By F. C. Craighead

With a Chapter on Abnormalities of Cell Structure

By I. W. Bailey

DOMINION OF CANADA
DEPARTMENT OF AGRICULTURE

BULLETIN No 37—NEW SERIES
(TECHNICAL)

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ENTOMOLOGICAL BRANCH

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(ENTOMOLOGICAL BULLETIN No. 25)

FIG. 1.—*Cacœcia fumiferana Clem.*, lateral view of pupa.

FIGS. 2 and 3.—*Cacœcia fumiferana Clem.*, two colour phases of adult female.

FIG. 4.—*Cacœcia fumiferana Clem.*, lateral view of sixth stage larva.

FIG. 5.—*Cacœcia fumiferana Clem.*, lateral view of fourth stage larva.

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TABLE OF CONTENTS

THE HISTORY OF PAST OUTBREAKS

The history of past budworm outbreaks in eastern America was given in Packard's Fifth Report, 1890, as completely as could be obtained from records and reports available at that time. An excellent record of injuries to spruce is also given by Hopkins, 1901, in his account of the depredations of the spruce bark-beetles in Maine. Reports of similar injuries published by Hough and Peck are quoted by the authors just mentioned and need not be repeated here in full.

Packard, 1890, p. 832, gives a detailed account of a typical spruce budworm outbreak in balsam and spruce which occurred along the coast region of Maine, from Portland Harbour to Penobscot Bay, lasting from about the year 1876 to 1880: " I was informed by the late C. J. Noyes, Esq., of Brunswick, who was a summer resident of Merepoint, that in June and the first week in July, 1878, the spruces and firs were attacked by great numbers of ' little measuring worms, like the currant worm in shape,' which eat the buds at the ends of the branches; since 1878 they had mostly disappeared, and in the summer of 1881 he had noticed only four or five.

" From Harpswell Neck we traced dead spruces and firs around to West Bath, where extensive forests had been destroyed and numbers of dead hemlocks were observed, while the wood was attacked and the bark undermined and perforated by buprestid borers, bark-borers, and the pine-weevil (*Pissodes strobi*). We have nowhere seen hemlock trees, which are more exempt than any other coniferous trees from the attacks of insects, so much infested.

" The death and destruction of spruce forests were reported to us at Rockland, Me., and at Calais, Me., the destruction having been observed by Mr. Sewall at the latter town in 1879. From these facts there is good reason to suppose that perhaps a third of the spruce and fir forests from near Portland to Calais have been destroyed by insects, most of the work of destruction having been accomplished four or five years ago, during 1878-'79.

" Similar damage has been done at points ten or twelve miles from the sea and in the interior of the state."

The same author also records serious injuries to spruce at about the same time in the interior of Maine as well as in the neighbouring states and in New Brunswick, but suggests that these outbreaks were probably caused by bark-beetles. The condition of the annual rings of old spruce and balsam in various parts of eastern Quebec and New Brunswick indicates a spruce budworm outbreak in those regions between the years 1879 and 1880; so that it seems probable that the budworm may have been the cause of much of the injury to spruce in the interior of Maine during that decade, and that the outbreak along the Maine coast may have been more extensive than Packard was led to suspect.

Packard also gives an account of a similar outbreak along the same part of the Maine coast seventy years earlier and it has been reported that the annual rings of old spruce in the eastern part of Quebec province indicate a budworm outbreak there at about the same time. On page 835 Packard says:—

" From Rev. Mr. Kellogg we learned the following interesting facts regarding the appearance of a similar, most probably the same, species of caterpillar even upon the same farm that was ravaged in 1878, early in this century. According to Capt. James Sinnett and Mr. John Jordan, of Harpswell, the spruces of Harpswell and Orr's islands were destroyed in 1807. Captain Bishops, whose son made the statement to Mr. Kellogg, cut down the dead spruces on these islands and worked six weeks boiling sea-water with fuel thus obtained in order to make salt. This was during the embargo which led to the war of

1812 with Great Britain. It is interesting to note that the bud-worm in 1878 appeared on the same farm on which the spruces had been destroyed by a worm in 1807, or about eighty years previous.

"During the season of 1886 and 1887, as in 1885, no traces of the caterpillar or moth of *Tortrix fumiferana,* formerly so destructive to firs and spruces, were discovered. The moths must be now as rare as before 1878. Great progress has also been made by the younger growth of these coniferous trees in repairing the desolation caused by the attacks of this worm."

Packard quotes a letter from Mr. R. H. Gardiner which may have reference to the same outbreak, l.c. page 817; "but would remind you of a fact that may be forgotten, that in the year 1818 every spruce tree west of the Penobscot was killed by an insect. I cannot remember this, but have often heard my father speak of it. From 1833 to 1836 I was interested in the lumber business on the Kennebec, and no spruce were ever seen among the rafts of logs, though spruce from the Penobscot was sold in Boston. Now little else than spruce is cut on the upper waters of the Kennebec, but every spruce tree has grown since 1818."

The numerous reports of injury to spruce during the last century in the forests from New York to New Brunswick, recorded by Packard and Hopkins, appear in most cases to refer to outbreaks by bark-beetles, but the description given in some of the accounts would apply equally well to a definite budworm infestation, and it is probable that the budworm was, in some cases at least, the primary cause of the injury.

Only a very few reports have been obtained of extensive injury to spruce in the provinces of Quebec and New Brunswick previous to the recent outbreak by the spruce budworm.

In his report on Forestry, 1882, quoted by Hopkins, 1891, Hough refers to large quantities of spruce timber dying along the Miramichi river in New Brunswick, about the year 1875. The hills suffered more than the valleys and the dense woods more than those in which partial clearings had been made. The greatest injury was to the largest and best timber, although the young growth was not wholly exempt.

In the same place he quotes from the *National Economist,* Ottawa, Canada, that "one operator in New Brunswick will cut 50,000,000 feet of spruce (1881) because of the damage done by insects, and to save it from total loss."

In the *Forester,* March, 1900, page 52, Mr. Austin Carey states that: "Old lumbermen tell of a great loss of spruce timber in northern Vermont and New Hampshire, extending into neighbouring lands in Canada, which occurred some thirty years ago. The drives of the Connecticut river are said to have been made up for some years thereafter largely of dead timber. The same region suffered again between ten and fifteen years ago."

Packard records, l.c., 819, that, in 1884, "Passing into Aroostock by railroad by way of New Brunswick, we learned that the spruces were still dying in portions of that province in great numbers. For example we were told that Mr. Gibson, of Fredericton, in the winter of 1882-83, sent parties up the Nashwaak river, a branch of the St. John, with the expectation of cutting 40,000,000 feet of spruce lumber; but half of it was found to be dead.

"In townships 8 and 9, on the headwaters of the St. Croix and Mattawamkeag, I was informed by a lumberman of unusual powers of close observation that the spruce trees had only been affected during the past five years. When he first went into the woods he found the trees dying and then advised the owners to fell them; this was the best possible advice but it was not taken."

In the Report on the Geology of Northern and Eastern New Brunswick, 1881, issued by the Geological Survey of Canada, R. W. Ells makes a brief refer-

tonus piceaperda Hopk.). The seriousness of the attacks of the spruce budworm is due chiefly to the fact that it attacks the buds which, in such a slow-growing tree, affects the growth considerably and repeated attacks will kill the tree. When visiting Vancouver island in October, I learnt that the infestation was increasing and found that the insect was attacking mainly the Douglas fir *Pseudotsuga mucronata* (Raf.) Sudw. In some ornamental grounds, it was also found that it had been feeding on larch, silver fir, Norway spruce, deodar and African cedar. Dr. Fletcher also found it attacking spruce trees in Manitoba in 1907."

In the Report of the Dominion Entomologist for 1911, page 231, this further statement is made:—

"The Spruce Budworm (*Tortrix fumiferana* Clemens). The inquiries and reports received by the division during last summer indicated that the depredations of the insect were more extensive than in the previous year to which reference was made in my last report. So serious did the situation appear, that many of the holders of timber limits were not unnaturally alarmed and feared the destruction of the spruce.

As the Department of Lands and Forests of the Government of the Province of Quebec has a body of forest rangers throughout the province, arrangements were made by Mr. G. C. Piché, Chief Forestry Engineer of the province, to obtain reports from them as to the distribution of the insect, and we drew up a questionnaire. The results of this inquiry and of the information which the Division of Entomology has received indicate that the insect is abundant in certain areas from lake Timiskaming on the west to lake St. John on the east and is sparingly distributed throughout the whole province down to the international boundary. The most serious devastations have been recorded from the region having river Desert and the upper Gatineau on the west to the Rouge river and lake Ouareau on the east, from the region southeast of lake St. John and from the river St. Maurice."

In the Report of the Dominion Entomologist for 1912, pages 180-181, an account is given of the studies of spruce budworm parasites carried out during the previous year. It was stated that "the devastation of the spruce budworm is spreading in an easterly direction and large numbers of anxious inquiries were addressed to the division by lumber companies and private owners.

In the Report for 1913, page 511, it is stated that: "The spruce budworm, *Tortrix fumiferana,* appears to be gradually spreading eastward, as more reports have been received from the region south and east of the St. Lawrence, and it is more in evidence in New Brunswick. Districts in Quebec, north of Ottawa, which were seriously defoliated in 1909, appear to have recovered from the attacks, and no cases of fatal injury have been discovered which could be ascribed to this insect, which is still under investigation."

In the Report for 1914, page 868, it is stated that: "The spruce budworm, (*Harmologa fumiferana*) has been reported from Ontario and Quebec woods less frequently than in the previous three years. It is apparent that its parasties have obtained control in many places and have saved the trees from further injury. An extensive outbreak appears to be spreading in the New Brunswick forests."

The first reports of the injury to spruce in Quebec were investigated by Mr. Gibson, as already stated. After a visit to one of the affected regions, the cause of the injury was determined as the spruce budworm, and a study of the life-history of the insect was at once undertaken on spruce near the Ottawa laboratory.

It is to be regretted that the studies made by Mr. Gibson and Dr. Hewitt were not published at the time; but it was not realized then how serious a matter the budworm outbreak would prove to be. During the few years following 1909 the spruce in the infested regions rapidly recovered its normal appearance, and since the injury to spruce was then the only concern of the lumbermen, anxiety with regard to the budworm outbreak very rapidly disappeared; but the knowledge then gained has, of course, made easier similar studies of the recent North Timiskaming outbreak.

At that time balsam was considered in most parts of Quebec to be a "weed" and little concern was manifested as to its possible injury by the outbreak. It was not until several years later, when the value of balsam for pulpwood began to be appreciated, that reports were received at Ottawa that on great areas in Quebec and New Brunswick the balsam was dead or dying very rapidly, and requests were made for control of the injury. A study of the situation was then undertaken by the Division of Forest Insects, with such time and assistance as could be spared from other work already in progress.

Trips to several of the diseased areas were undertaken and in some of these areas it was found that, even though the greater part of the balsam was dead or in an apparently dying condition, the caterpillars and moths of the spruce budworm had by that time entirely disappeared, and, since no such result as this had been anticipated from the budworm outbreak, the connection between the budworm and the death of the balsam was not at first fully appreciated, and too much importance was placed on the work of the bark boring beetles, the balsam weevil and the balsam bark-beetle.

The work of the second summer in Quebec and an examination of conditions in New Brunswick made it clear that the spruce budworm outbreak was the primary cause of the whole trouble and that the beetles were only attacking weakened trees which had lived through the original budworm outbreak.

In the Report of the Dominion Entomologist for 1916, page 40, it is stated that: "The outbreaks of the spruce budworm, *Harmologa fumiferana,* recently so severe in Quebec province, have largely subsided. In at least one instance a considerable area of spruce has died, probably from bark-beetle attacks upon trees already weakened by the spruce budworm injury. As a rule, the budworm injured spruce has completely recovered. The most serious injury has been to very young and to mature stands of balsam; many of these trees have died from the repeated defoliation."

In the Report of the Dominion Entomologist for 1917, page 13, it is stated that: "On account of reports of dying spruce in Quebec, two trips were made by Mr. Swaine on the Black and Nation rivers respectively. Injury by *Polygraphus rufipennis* was found, but none by *Dendroctonus.* Throughout Eastern Canada the balsam is dying in large numbers from various causes and this matter is now under investigation. We propose to undertake co-operative studies with the forest plant pathologists of this and certain other diseases, as it is felt that such joint work will result in a quicker elucidation of a number of obscure troubles than separate endeavour on the part of entomologists and plant pathologists.

In 1919 and 1920, forest sample plots were established in co-operation with the foresters of the Commission of Conservation. Several of these plots were in budworm-injured areas on the Boule river and at lake Edward in Quebec, and near Bathurst and Newcastle, N.B. They have since been used in following the effects of the injury over a period of years.

In the summer of 1920, in the course of forest insect surveys about lake Abitibi, a spruce budworm outbreak was discovered crossing the Timiskaming and Northern Ontario railway near the towns of Otter and Engelhardt, in the province of Ontario. About the same time a report of dying balsam on a large area about Long lake, north of lake Timiskaming, was received from Mr. Roger Gibson, Forest Ranger for that territory.

balsam forests appeared greyish from above, first to a more lightly infested region in which the defoliated areas of balsam were more scattered and paler in colour, and finally over solid green timber which had not yet become noticeably affected. In the eastern part of this section the outbreak had increased in intensity and became more evenly distributed since the previous summer, and its western boundary had apparently moved about twenty miles further west.

The northern flight passed over the eastern end of lake Des Quinze, Long lake and Island lake, nearly to the shores of lake Abitibi, and it could be determined that the northern boundary of the outbreak stretched east and west some miles north of Island lake. On the northward and eastward flights the survey passed over a hundred miles of forest where the high percentage of dead and dying balsam gave a general tone of gray to the whole country, and finally, east of lake Expanse, the flight was again over a green forest in which from 90 to 100 per cent of the balsam was dead and fallen and, therefore, not visible at all from the air.

Before completing the maps of the Timiskaming region a long eastern trip from Haileybury to Grand Lake Victoria via lake Expanse and lake Dumoine was undertaken. This route crossed the whole length of the heavily infested country and passed into the region from which the outbreak had apparently spread and in which the balsam was known to be almost entirely killed. By alighting on lakes at several places and studying the neighbouring timber it was hoped to determine the history of the Timiskaming outbreak and perhaps discover important factors concerned in its development.

An accident to the plane near lake Dumoine curtailed the work in that area and the survey returned by canoe through the Kipawa district to Kipawa lake near the southern end of lake Timiskaming.

Although the flying programme was not entirely completed, the most important information sought was satisfactorily obtained.

The infestation may be described very briefly in this way. Westward of lake Timiskaming the budworm outbreak was severe and fairly generally distributed for about thirty miles, gradually becoming less evident from the air, and finally disappearing west of Martin lake and Red Cedar lake southwest of lake Temagami. Northwest of lake Timiskaming the injury had not spread so far and had only reached the eastern shore of lake Temagami. Directly north of lake Timiskaming is a large section over which flying was impossible, owing to lack of landing water. This country, much of which is cultivated, was covered by ground surveys and the outbreak was found to extend a short distance west of the Timiskaming and Northern Ontario railway, crossing near Englehart, about twenty-five miles north of the lake.

From Long lake, north of lake Timiskaming, eastward to the eastern end of lake Expanse was found the main centre of active budworm outbreak. In this area, north to the height of land and crossing it in at least one section, nearly 50 per cent of the balsam is already dead and probably 90 per cent of it will be dead within the next five years. In the western part of this area the injury is only two years old and the whole country is gray with dying balsam. About the eastern shores of lake Expanse the outbreak is older and many red top balsams are everywhere abundant. About twenty miles southeast of lake Expanse the evidence of the injury seen from above disappears and long before lake Dumoine is reached the forest appears entirely normal. The reason for this was found through a ground survey made about lake Dumoine and on the way down the Kipawa. Throughout this whole country between lakes Dumoine and Kipawa the balsam is almost entirely dead and in great part already fallen.

In a well watered country such as that covered by this survey work, a hydroplane survey is a wonderfully rapid and effective method of obtaining general information under such conditions as a balsam budworm outbreak produces, in which the changed colour of the injured trees can be identified readily from above. While effective observations can be made, if the visibility is good, from a height of over 4,000 feet, the most satisfactory height for this work was found to be between 2,500 and 3,000 feet. Since it is necessary, for safety, to keep within volplane distance of landing water, that is, roughly, a thousand feet of altitude for a mile, one is sometimes obliged to fly rather high over very interesting country. This obstacle can be avoided only by coaxing the pilot. It was a wonderful advantage to be able to alight on lakes, make a ground examination of conditions and then to fly on to other sections. It should be noted that the risks of the work are connected chiefly with landing upon and with rising from small or narrow lakes in a hilly country. Landings should, therefore, be made only when they are of real advantage and the landing water should be carefully selected. In the machine used on the survey four men were carried besides a small amount of baggage. The latter is reduced, of course, to the bare necessities and emergency rations and equipment in provision for accidents.

When possible to arrange it, two observers should be carried, one mapping the country on each side of the machine. Even then it will sometimes be advisable to make two trips over particularly interesting sections.

A ground survey over the territory covered in the two weeks flying would have occupied a survey party for at least two seasons and would have given only a very small part of the information that was obtained from the air. In the view from the air, with the whole country spread out below, the distribution of the timber types, the more immune black spruce areas, the hardwood areas, the areas of dead balsam and the relations of the infestation to the different timber types, as well as the distribution of the outbreak, may be determined more accurately than by any type of ground survey that could be imagined. The air survey must be carried out in conjunction with an intensive survey of conditions from the ground in selected areas so that each type of study supplements the other. The air survey in addition to determining the area of the infestation discloses the best localities for sample plots and other study areas, and the use of air machines makes it possible to utilize for study purposes areas that would be inaccessible by ground travel. On the other hand after a study and careful location of the various types of infestation from the ground an examination of these from the air gives data for interpreting the conditions on the whole area. For obtaining data of this general type the advantages of the air survey are unique.

HISTORY OF THE PRESENT OUTBREAK AS BASED ON RING RETARDATION

One of the most important features of the budworm epidemics from the standpoint of future recommendations for prevention or control is to determine an accurate history of the origin and spread. If these outbreaks originate in and cover enormous areas in one or two years it is obviously impossible to adopt artificial methods of control. On the other hand if the development of an outbreak covers several years in a limited area it might be possible by concentrating every effort to prevent its spread.

Due to the conflicting nature of many reports on the appearance of the budworm in many localities and to the fact that its presence is usually not observed for two to three years after the first feeding, or until the trees begin dying, such evidence is unreliable in outlining its origin and spread. Fortunately the feeding is accurately recorded in the annual rings so that it is possible by means of these rings to reconstruct the history of the outbreak accurately if a sufficient number of localities are observed. Due to the enormous territory

border and in adjoining areas of Maine and Quebec to decide whether this outbreak was independent or spread from bordering territories. In the vicinity of Machias, Me., examinations of trees showed the first feeding to have been the same year, 1913.

The outbreak centering about lake Opasatika began in 1918. An area of 150 miles north and south and 100 miles east and west was invaded that year. The northeastern limit was not ascertained but since the Grand Lake Victoria region was so thoroughly devastated from 1909-14 it probably only extended to meet this previous outbreak.*

PHENOLOGICAL OBSERVATIONS

The following table shows the range in time of plant and insect activities in the budworm injured territory. This information serves a useful purpose in timing one's visits to the various observation points.

DIFFERENCES IN TIME IN PHENOLOGICAL EVENTS IN QUEBEC AND NEW BRUNSWICK

Locality	Latitude	Longitude	Elevation	Days later than Ottawa	—
	"	"			
Ottawa, Ont.	45–20	75–45	300	0	
Temagami, Ont.	47–10	79–40	1,000	6	
Lake Opasatika, Que.	47–50	79–25	900	15	Northwestern Quebec.
Flamand, Que.	47–40	73–15	900	22	North of Montreal.
Quebec, Que.	46–40	71–10	0	5	
Fief St. Claire, Que.	47	70–20	200	7	South Shore St. Lawrence.
Chicoutimi, Que.	48–20	71	0	20	Near lake St. John.
Clarke City, Que.	50–15	66–40	0	21	North shore St. Lawrence.
Gaspe Basin, Que.	48–45	54–30	0	25	Tip of Gaspe peninsula.
Pisiquit Brook, N.B.	47–20	65–20	200	20	Northeastern New Brunswick.
Caines River, N.B.	46–20	66–15	200–300	14	Mirimichi plateau.
Wayerton, N.B.	47–10	66	500	17	

DESCRIPTIONS OF THE STAGES OF THE BUDWORM

The following descriptions have been prepared by Mr. Arthur Gibson. A fuller description of these stages will be published elsewhere.

The Egg

Colour, pale green, noticeably paler than leaf upon which deposited; surface distinctly reticulated (under a lens); oval in shape; laid overlapping each other like the scales on a fish.

The Larva (figs. 4 and 5)

When newly hatched the larva is 2 mm. in length, of a pale yellowish-green colour with a dark-brown head. It changes colour with age and when mature is about an inch in length, tapering slightly from the middle to the end, of a dark-brown or dark reddish-brown colour, with conspicuous whitish-yellow piliferous tubercles; setæ long, slender, brownish in colour, stigmatal band yellowish, wide, narrower on the posterior segments. Head black, shining, mouth parts paler. Prothoracic shield brownish, paler anteriorly, with a distinct pale median line. Thoracic feet mostly blackish-brown, shining, with bands of white between blackish plates. Prolegs concolorous with ventral surface, which is paler than dorsal surface; crotchets brownish.

* Since the preceding was written the first year of feeding has been determined at several points, namely; 1910, southern Quebec just north of the N.H.-Ver. line; 1910, near Moosehead lake, Maine; 1913, northeastern N.B.; 1914, Great Salmon river, N.B. A distinct outbreak also devastated certain sections of western Ontario, and northern Minnesota. The first feeding there probably commenced in 1912.

The Pupa (fig. 1.)

Length 14 mm., width at widest part 5-6 mm. At first the pupa is of a pale creamy colour with conspicuous brown bands, it soon changes to a pale brownish-yellow colour, then to a pale reddish colour and finally to a darker reddish-brown with transverse bands and spots of blackish-brown. The abdominal segments have dorsally two transverse rows of short, stout spines, those on the immediate anal segments not so conspicuous. Whole surface of pupa roughened, particularly on dorsum of abdomen. Cremaster dark brown, bearing eight curved stout spines, four of these are together at the posterior end, and the other four are separate, two on either side.

The Moth (figs. 2 and 3).

As will be seen from the frontispiece, the moth is very variable in markings; there are also distinct colour varieties, but the predominating form in Eastern Canada is of a dull grey colour, the forewings overlaid with bands, streaks and spots of brown. In the middle of the upper margin of the front wings there is a rather large conspicuous whitish spot. The moth expands about seven-eighths of an inch when the wings are spread.

SECONDARY INSECTS ASSOCIATED WITH THE BUDWORM

The following descriptions are intended to give a general picture of the characteristic features of the insects associated with the budworm outbreak so that they can be recognized under field conditions. Less attention is given to the adult descriptions and more to the larvæ and the characteristics of the work. All characters taken together with the host plant in which they are found should distinguish them from other associated insects of minor importance.

Characteristic Features and Seasonal History of the Insects

The Destructive Eastern Spruce Bark-beetle, *Dendroctonus piceaperda* Hopk. (Pl. XXIII). This is the largest bark-beetle found in spruce, varying from 5 to 6 mm. in length. It is a rather robust beetle, brown or black when mature, with head, thorax and abdomen black and the elytra reddish-brown to black. The larvæ are curved, legless, yellowish-white grubs with a strongly chitinized head and a dark chitinization on the dorsum of the last two segments. The beetles are found in egg-tunnels from 4 to 10 inches long and about 5 mm. wide, running mostly with the grain of the wood, which they score only to a moderate degree. Pitch-masses are usually found exuding from the entrance hole through the bark. The eggs are laid in alternate layers along the sides of the egg-tunnels. The larvæ bore in the inner bark at right angles to the egg-tunnels, scoring the surface of the wood only at the outer ends of their mines, and the pupæ are formed in the ends of the larval mines in small oval cells between the bark and wood.

Overwintered adults begin to emerge from the bark and attack new trees about two or three weeks after the balsam buds open. Other beetles continue to attack throughout the summer from delayed development of the previous year's brood. Many adult females leave the trees first infested and attack a second tree in midsummer, so that the period of attack is distributed throughout the entire summer. The first larvæ mature in about two months, pupate and transform to adults which remain in the trees throughout the winter. Later developing larvæ overwinter in the larval stage, pupating the following season.

This beetle affects all species of spruce found in Eastern Canada preferring the dying bark of windfalls and fresh stumps, but when in large numbers readily attacking and killing the largest and finest trees, the smaller trees, less than 10 inches, D.B.H., are less commonly attacked.

The Four-eyed Spruce Bark-beetle, *Polygraphus rufipennis* Kirby. (Pl. XXI, fig. 1). A small, black, stout beetle, 2 to 3 mm. in length, having the eyes divided into an upper and lower lobe. The beetles excavate radially branched tunnels from 1 to 2 inches long and about 2 mm. wide extended usually in the inner bark without scoring the wood. The larvæ feed mostly in the inner bark and pupate either there or between the bark and wood.

The main flight occurs in the early season beginning when the balsam buds open. Scattered attack takes place throughout the entire summer from delayed emergence and females leaving the egg-tunnels first constructed. The larvæ from the spring attack mature and pupate in two months, the resulting adults, however, remain in the cells until the following spring. Overwintering takes place in either the adult or larval stages.

It attacks larch and all species of spruce, and is found abundantly in slash, windfalls and weakened trees.

The Balsam Bark-beetle, *Pityokteines sparsus* Lec. Pl. XXII, fig. I). A small, black, somewhat slender beetle, 2.3 mm. in length, the only bark-beetle found mining under the bark on the trunks of balsam. The beetles excavate somewhat symmetrically radiating tunnels, 1 to 2 inches long and 2 mm. wide, arising from a central chamber, and deeply scored in the wood. The larvæ feed between the bark and the wood and pupate usually in the outer sapwood, or between the bark and the wood.

The adult flight and seasonal history are similar to those of *P. rufipennis.* It attacks only balsam.

The Canadian Spruce Bark-beetle, *Ips perturbatus* Eichh. (Pl. XXI, fig. 4). This is a stout bark-beetle, 4 mm. to 5.5 mm. in length, brown to nearly black in colour, with the posterior face of the wing covers excavated and armed with four distinct teeth on each side about the margin of the cavity. It is distinguished from allied species by its stout form, usually large size, long, erect pubescence, the punctuation and pubescence of first two elytral interspaces and the arcuate dorsal profile of the elytra.

The tunnels are found chiefly in white spruce, lying between the bark and the wood of the middle trunk. Either two or three longitudinal egg-tunnels are cut, extending upward and downward from a central shallow chamber, engraving both bark and wood. The larval mines lie chiefly in the inner bark and radiate outward and then upward or downward from the sides of the egg-tunnels.

The attack extends over the greater part of the summer, with probably only one complete brood each season.

The Northern Spruce Bark-beetle, *Ips Borealis* Swaine. (Pl. XXI, fig. 3). This species is smaller and more slender than *perturbatus,* 3.25 to 4 mm. long, with the elytra more closely punctured, bearing a row of punctures along each interspace, and the front of the head smooth and shining.

The tunnels are similar to those of *perturbatus* but smaller and more slender. The species occurs in all species of spruce and is found throughout the northern spruce forests of Canada.

The Eastern Longtoothed Bark-beetle, *Ips longidens* Swaine. (Pl. XXII, fig. 2.) This is distinguished from the other allied species found in eastern spruce by the small size, 2.5 mm. to 3.5 mm. in length, slender form, straight and transverse sutures of the antennal club, deeply, closely punctured elytra and the peculiar armature of the declivital excavation with three teeth on each side, the third being longer than the others.

The tunnels are somewhat similar to those of *borealis* and *perturbatus* though much smaller and often more distinctly star-shaped in arrangement. The species is not usually common in southern Canada, but has been found to occur abundantly in the more northern localities in spruce suffering from previous budworm injury.

Dryocœtes americanus Hopk. A dark, reddish brown bark-beetle, 3 mm. to 4 mm. long, with the declivity of elytra convex and the antennal club subglobular and obliquely truncate at the apex. Distinguished from the species of *Ips* found in spruce by these last two characters and from *Polygraphus* by its more elongate form, lighter colour, different antennal club and entire eyes.

This species occurs everywhere throughout our coniferous forests in dying bark of spruce, pine and larch, excavating its tunnels entirely in the middle and inner bark.

Dryocœtes affaber Mannh. This species is similar to *americanus* in form and colour but very much smaller, 2.3 mm. to 2.75 mm. in length, in the eastern form. The tunnels are found only in dying bark, and are common throughout our eastern forests.

Spruce Bark-beetles of Minor Importance

Several other species of bark-beetles may often be found in dying spruce bark, usually following the earlier attack by *Dendroctonus, Ips* or *Polygraphus.* The following occur in spruce in eastern Canada:—

Dendroctonus valens Lec.
Scierus annectens Lec.
Hylurgops pinifex Fitch.
Phthorophlœus piceæ Sw.
Crypturgus atomus Lec.
Eccoptogaster piceæ Sw.
Pityophthorus nitidus Sw.
Pityophthorus opaculus Lec.
Pityophthorus nudus Sw.
Pityogenes hopkinsi Sw.
Ips chagnoni Sw.
Ips pini Say.
Orthotomicus cœlatus Eichh.
Gnathotrichus materiarius Fitch.
Trypodendron bivittatum Ky.

The Balsam Bark Weevil, *Pissodes dubius* Rand. (Pl. XX.) The adults of this species are rarely seen. It is greyish-brown in colour, 5 to 8 mm. in length, mottled with black and white and having the head produced into a curved beak about half the length of the body. The larvæ are curved, whitish, legless grubs, found in long, straight or sinuous mines increasing gradually in width, lying between the bark and wood and radiating from a common point. The eggs are laid in groups in the inner bark through punctures made by the beak of the adult. In dying or dead trees the young larvæ bore immediately between the bark and wood and extend their mines from six to twelve inches in all directions but more closely grouped above and below the egg punctures and roughly parallel to the grain of the wood. If the tree is living and the attack unsuccessful, the larval mines are extended entirely in the bast from one to six inches before the larvæ die. The pupal cell is a characteristic nidus-like structure deeply embeded in the wood at the distal end of the tapering larval mine.

Small pitch masses collect at the feeding and ovipositing punctures and flow from one to several inches down the trunk. On trees much weakened by defoliation practically no pitch exudes and it is impossible to detect the infested trees by this character. Oviposition is confined chiefly to the base or lower third of the trunk, and the exposed roots are frequently attacked.

The adult beetles emerge in the late summer and hibernate in the leaf litter. Probably some feeding takes place before hibernation. At the time the balsam buds open the adults are again active, but do not oviposit until some weeks later. In case of successful attack the larvæ mature in from eight to ten weeks, but the adults do not emerge until the next summer. This two year life cycle is sometimes well shown by alternate years of abundance of the insects.

The Spruce Weevil, *Pissodes rotundatus* Lec. This beetle is closely allied to the balsam weevil but is distinguished by its somewhat smaller size, more reddish colouration and less conspicuous white markings. The habits, seasonal history and character of work are similar to those of the balsam weevil. It breeds entirely in spruce as far as is known.

The Black Sawyer, *Monochamus scutellatus* Say. A large, cylindrical, shining black or black and white speckled beetle with a white scutellum, from 18 to 28 mm. in length and having slender elongate antennæ, as long as the body in the case of the female or twice as long in the male. The larva is elongate, cylindrical, yellowish-white and legless, having the dorsal surface of the prothorax strongly veloured and the abdominal segments covered with four rows of finely asperate tubercles. The eggs are laid in small conical slits gnawed through the bark. The larvæ feed beneath the bark scoring the wood in a large irregular patch four to six inches across. When about half grown they excavate a long deep tunnel through the wood, curving it roughly in a U-shaped manner to meet the surface of the wood again. When full grown a pupal cell is constructed at the extremity of the mine, separated from the surface by a thin layer of wood. Throughout the feeding period large quantities of fibrous frass are exuded from a small oval hole through the bark. Beneath the bark the larval mine is packed with fibrous frass and a plug of this material is placed at the entrance of the hole into the wood before the larva pupates. These extensive mines beneath the bark frequently destroy a large part of the bark-beetle broods, through the destruction of their food supply.

In from ten days to two weeks after the balsam buds open the beetles begin emerging and seek green trees where they feed on the leaves, and young bark. The effects produced by this feeding are the same as described for *M. marmorator*. About two weeks later the first eggs are laid. In the vicinity of Ottawa, larvæ developing from eggs laid in June enter the wood in from four to six weeks, and complete their growth by fall. Pupation occurs about a month before the beetles emerge the next year. Slower development in some individuals produces an overlapping of generations so that adults are emerging throughout the summer until about the middle of August. The broods from these late beetles emerge late in the following summer or even may hold over to the next spring. In localities where the balsam buds open two or three weeks later than at Ottawa, about June 1st, two years are required to complete the development, the entire second season being spent in the wood. A few individuals come through late the first season following oviposition, usually in July. Here also a slight overlapping results, but the greater part of the emergence is concentrated in a very short period of a month following the opening of the balsam buds.

The Balsam Sawyer[1], *Monochamus marmorator* Kirby. (Pl. XXIV). This large, beautiful beetle, of the same size and form as *M. scutellatus,* is mottled with white and tan coloured spots. The larvæ are quite similar to those of allied species, and can be distinguished only by the slightly coarser asperites on the pronotum and ampullæ and the more orange-coloured peritreme of the spiracles, which are also slightly more oval.

Since the habits of this insect have never been described, more detailed discussion is given than in the case of the other species. It has previously been quite a rare insect in collections, probably due to its nocturnal habits; but has been found very abundantly nearly everywhere that balsam occurs in Quebec and New Brunswick.

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[1] Packard, 1885, gives a good description of the habits of *Monochamus confusor* Kirby, which no doubt refers to this species.

Seasonal History. The first emergence of the adults at Ottawa occurs during the last week in June, and extends through the middle of July. The adults feed for about two weeks before ovispositing.

The young larvæ hatch in about three weeks and mine extensively in the bast. By the end of the season about half the larvæ have entered the wood; the others remain under the bark or in the bark. The following spring the mines are rapidly extended in the wood and by the middle of May the pupal cells are constructed. On June 1 the first pupæ were observed and many were nearly ready to transform. Part of the brood transforms the first year while a portion remains over until the following season, or all may go over to the second year, depending on the vitality of the trees at the time of attack, which influences the larval feeding in the bast.

In more northern localities, the greater part of the brood do not complete their development until the second year. This is the case at Long lake, Que., and in the Kenogami watershed, Que. At Long lake, due to the two-year life-cycle, the adult emergence is relatively earlier coinciding with that of *scutellatus.* Several individuals were found emerging in late July of the summer following oviposition. Ovipositing extends to the middle of August.

Feeding of the Adults. After emerging the adults fly to the tops of green trees and feed for two or three weeks before ovipositing. The new leaves are eaten usually by biting notches from one side thus giving the leaf a ragged, saw-like appearance. Also, the bark of the smaller twigs is eaten. The bark is removed in patches of from one-half to one inch long on the lower surface of the twigs. These scars produce a very characteristic twig blight on balsam. During the autumn following the feeding, or the next spring, the branches turn yellowish-brown and, finally, to the characteristic reddish-brown of dead balsam. The leaves persist during the next summer in this condition. Feeding of the adults continues each day during the life of the beetle.

Oviposition. Egg-laying takes place at night. On warm sultry evenings the beetles crawl about on the trunks. Few were found until after dark. The female is usually accompanied by the male. The former selects a point beside or directly over a gum blister, and gnaws a small transverse slit in the bark, 4 to 6 mm. long. The ovipositor is thrust into the centre of this slit producing a ragged oval hole, $1\frac{1}{2}$ to 2 mm. in diameter, and causing the bark to break slightly at each side. The egg is placed far back behind the cavity of the gum pocket. A decided tendency is shown to oviposit in patches and on the lower trunk and base of more thrifty trees.

This characteristic of selecting gum blisters causes a copious pitch flow from the wound, which flows down the bark in long bands and readily distinguishes the trees.

Characteristic Features of the Work. The egg scars most readily distinguish the attack of this beetle from that of *M. scutellatus.* The opening for insertion of the egg is much larger and more ragged. The young larvæ feed within the bast tissue until the first moult and even longer on trees that are more thrifty or on which large quantities of eggs have not been laid. Considerable brown frass is exuded from the bark. The mines beneath the bark are extended crosswise until the tree is completely girdled, these often extending 6 to 12 inches around the tree. Much of this frass is packed tightly behind the larvæ consisting of brown granular bark and white shredded wood fibres. Not until the larvæ begin boring into the wood is much frass exuded through an oval hole similar to *scutellatus.* The more advanced larvæ bore deep into the wood by the end of the season. Next spring the burrow is continued to form the pupal cell. On standing trees the mine in the wood is broadly U-shaped, usually in a plane parallel to the axis of the tree and is not extended as deeply into the wood as in the case of *scutellatus*. The upper end is separated from the surface by a thin layer of wood and bark. This is gnawed away by the adult when emerging. The exit hole is circular. The extension of the larval mine in the wood is for the greater part tightly packed with fibrous frass. Only the upper end is open, which is slightly enlarged to form the pupal cell.

Less mature larvæ winter in the bast or beneath the bark. All the larvæ that enter the wood plug the entrance hole late in the season. This feature is not characteristic of *scutellatus* which only plugs the entrance to the wood before pupating.

The long period of feeding in the bast of living trees and the crosswise character of the larval mines beneath the bark enables this species to attack living trees.

The Spruce Ambrosia Beetle, *Trypodendron bivittatum* Kirby. This is a small, black, rather stout, cylindric beetle, 3 mm. in length and 1.2 mm. wide, having two longitudinal stripes of yellowish brown on the elytra and a yellowish area on the disc of the pronotum. The beetles bore directly through the bark into the sapwood for a short distance making a small hole about the thickness of the lead in a pencil. From one-half to one inch within the wood surface the entrance tunnel branches at a wide angle into two egg-tunnels along the sides of which the eggs are laid in shallow cup-shaped egg-niches. These are extended by the larvæ to about 4 mm. in length and in these cradles the larvæ develop. The white meal-like frass exuded from the entrance holes is a characteristic feature of the work. The walls of the tunnels are rapidly covered by a layer of a peculiar fungus, which forms the chief food for both adults and larvæ, and eventually stains the tunnel walls dark brown or black, giving them the appearance of having been burned with a hot wire.

The beetles begin attacking suitable trees about a week before the balsam buds open. Two months later the new beetles emerge. A second attack has been recorded from the southern portion of Eastern Canada. In more northern localities no evidence of the second brood was observed.

The Four-eyed Spruce Borer, *Tetropium cinnamopterum* Kirby. An elongate, cylindric beetle, 10 to 14 mm. in length, of a uniform dull slaty-brown colour with darker thorax and having the eyes divided into an upper and lower lobe. The larvæ are elongate cylindric having the head wider than long and beset with numerous long hairs on each side. The apex of the mandible is oblique and rather blunt and the pronotum and dorsal and ventral surfaces of the abdominal segments velvety pubescent. The ninth abdominal segment bears a small, bifurcated, conical spine.

The eggs are laid in crevices of the bark, and the young larvæ mine extensively beneath the bark, later, as they mature, entering the wood or bark to form a pupal cell. The larval mines are packed with mixed granular and finely shredded frass.

The main flight of adults occurs two or three weeks after the spruce buds open and individuals can be found less abundantly throughout the summer. The development is completed in one year though many individuals require a partial second season.

Leaf Feeders. Two species of defoliators have been found quite abundantly in the later years of the budworm cycle. In both cases the habits are quite similar to those of the budworm. One of these, *Tortrix alleniana* Fern., was quite numerous at Lake Opasatika, Que., in 1921, and was taken by Mr. Gibson in the previous outbreak at Maniwaki, Que., in 1919; the other, *Dioryctria reniculella* Grt., was recorded by Mr. J. N. Knull as being very abundant in 1922 at Bathurst, N.B.

LOSSES INCURRED THROUGH BUDWORM OUTBREAKS

Since the year 1909, the great outbreaks of the spruce budworm have swept the major part of the Quebec forest south of the height of land, nearly all the province of New Brunswick and smaller areas in Nova Scotia and Ontario. The actual budworm outbreak, during which the caterpillars were feeding, lasted usually for only four years in each locality and then died away, so that often no further trace of the feeding was to be seen without careful search.

The extent of the mortality depended upon the ability of the trees to recuperate from the budworm feeding. The injury varied from a very small percentage of mortality or even a reduction of annual increment to an almost total loss of the balsam content of the forest. In old, mature forests, where the injury was heaviest, and especially on thinner soils, between 50 and 70 per cent of the balsam in the stand died within the first four years as a direct result of the budworm defoliation. During the subsequent five or six years the balsam continued dying, more or less rapidly, until on many thousands of square miles, between 80 and 90 per cent of it is now actually dead and dry or will certainly become so within the next few years. In the country between Lake Kipawa and Grand Lake Victoria practically all the old balsam stand is dead and fallen; in the more recent Timiskaming outbreak north of lakes Des Quinze and Expanse, more than 50 per cent of the balsam is already dead and most of the remainder appears to be dying rapidly.

In younger forests a return to normal vitality may be established shortly after the feeding stops with only a loss of the suppressed or weaker trees, not exceeding 15 or 20 per cent of the stand, and a general loss of increment. Some sections of southern Quebec and the Restigouche country of New Brunswick are examples of areas where the injury was relatively light. The combined effects of borers in the sapwood and heart rotting fungi make the trees very susceptible to windfall. The final condition of these injured areas is a tangled mass of fallen trunks and tops with scattered birch still standing. Even the living spruce under such conditions, losing the support of surrounding balsam, often goes down. In considering the total loss we must include the distortion of trees through dead terminals, the loss in annual growth on trees that recover, and the extra fire hazard caused by the accumulated debris, as well as the dead timber.

Terminal Injury

The injury to the terminals of trees recovering from the outbreak is of much importance in the consideration of the total losses from budworm epidemics. In all stands where the mortality is 10 per cent or more, except mixed hardwood types, 75 to 100 per cent of the trees which recover have from one to five feet of the terminal killed. When we consider that the entire injury of the white pine weevil consists of destroyed terminals alone the enormous effect of this one feature can better be realized. The terminal portion of the trees first assumes normal growth following defoliation, though it is questionable if these trees, except in young stands, ever regain normal height development. Depending on the length of terminal killed and the density of the stand, one or several new leaders are developed, causing a very characteristic bunched top. Just below this top a break in foliage density altering the symmetry of the crown indicates the point where the older terminal was killed. When the injury occurs below the merchantable height it will often result in a poorly formed stem. In balsam the breaking of the dead terminal possibly opens the stem to infection by the serious brown heart-rot, *Stereum sanguinolentum*.

Loss of Increment

Referring to the figures showing the reduction of width of the annual rings for a period of some ten years during and immediately following the defoliation it can be readily seen that through this source alone considerable loss is entailed. Not only the balsam that recover are so affected, but all species of spruces as well. No attempt has been made to estimate definitely this loss based on volume of wood laid on for a ten-year period previous to the outbreak as compared with that found during the ten years following. Rough computations on some five hundred trees sectioned and examined for other purposes would indicate that at least a total of three to five years' increment has been lost. Since this loss has apparently occurred throughout the whole budworm swept area of Quebec and New Brunswick, the total actual loss in wood volume through this cause is enormous.

Windfall

The wood of the dead balsam deteriorates very rapidly, through the agency of wood borers and heart rotting fungi, so that the trees usually break off within two or three years after their death. Heavy winds hasten this process, and as the forest becomes opened up through falling of the dying and dead trees even many of the remaining healthy balsam and spruce are overthrown. The result on very great areas has been that within ten years of the beginning of the budworm outbreak a green and apparently healthy forest has been converted into a tangled area of wreckage with scattered hardwoods, a few spruce, and dead balsam stubs as its only timber supply.

Increased Fire Hazard

It is evident that in a forest such as that just described, with the forest floor littered with dry debris from dead balsam and spruce, the result of general windfall, the danger from fire must be increased to a very great degree.

In many places the ground is now covered with a thick stand of balsam reproduction which would insure a future crop of pulpwood if it could be protected from fire. It is growing thriftily now, since the opening of the stand; but mixed with this reproduction is an ever increasing, tangled mass of dead tops, accumulating as the rotting trees break off. A fire under such conditions will kill everything, destroy the soil and leave a barren waste. Two enormous fires in just such a region were witnessed recently and there was no doubt that their magnitude and severity were directly due to the dead balsam in the forest through which they swept. These areas of dead timber are veritable fire traps, and will prove a serious menace to the whole region until the mass of combustible material has disappeared, since fires originating there can rapidly gain proportions beyond all human power of control. It is evident, therefore, that these conditions created by the budworm outbreak will make fire fighting in many parts of Quebec and New Brunswick much more difficult and very much more expensive for some years to come.

Loss of Timber Values

It has proven impossible to make an accurate estimate of either the amount or value of the timber killed or of the very great loss of increment suffered by even the trees which eventually recovered throughout the whole budworm swept area. On the greater part of the country, particularly that vast region immediately south of the height of land in Quebec, no careful estimate of the original balsam stand had ever been made so that any statement of losses made at this time can at best be only approximate.

It is possible that a portion of the timber killed in the outbreak, located in the more inaccessible regions, would not have been utilized during the normal lifetime of the original stand, and should, therefore, not be considered in an estimate of commercial values. Judging from the present outlook every balsam and spruce south of the Height of Land, and most of the timber to the northward, will be owned and valued by someone before the next ten years are past; and even if these great losses had not taken place, very little balsam would have escaped utilization in the great pulp-mill development that such a vast supply of timber would have engendered.

It should also be realized that those less accessible areas are now growing a new crop of balsam, which may be of more value to the future than the old stand would have been.

Loss in the Province of Quebec

The timber killed in the province of Quebec was almost entirely balsam fir. Only on the south of the St. Lawrence river was any considerable amount of spruce actually killed, and no separate estimate of its value has been made. These forests are typical of New Brunswick conditions and the percentage of losses are similar.

On a wide belt lying immediately south of the Height of Land, stretching from lake Kipewa to the eastern limits of the Saguenay drainage basin, about 500 miles in length and varying from 50 to 150 miles in width, a very high percentage of the balsam was killed. On large sections of that area between 90 and 100 per cent of the original stand of balsam is now dead and fallen. Part of the region between the headwaters of the Gatineau and the headwaters of the St. Maurice is apparently exceptional in that a considerable part of the balsam stand has survived. It will probably be a conservative estimate to consider that over 80 per cent of the commercial balsam on this whole strip of country has been killed.

That section of Quebec between the north shore of the gulf of St. Lawrence and the height of land northward of the Saguenay drainage basin has not been explored by any entomologist. Reports from this large area are so conflicting that no statements of losses are possible.

In the more southern part of the province, south of the Saguenay river and exclusive of the tip of the Gaspe peninsula, the loss has varied from 70 to 80 per cent in sections on the Rouge and Devil rivers to 15 or 20 per cent in parts of the St. Maurice valley and some sections south of the St. Lawrence river. On all this area the average loss must have been at least 25 per cent of the original balsam stand.

One of the largest companies operating in the province of Quebec has, after careful study of the situation on their limits, written off fifteen million cords or one-half their estimated timber stand. It does not seem probable that the area under consideration, about 10,000 square miles, suffered more than one-tenth the total loss for the province.

Mr. Frank J. D. Barnjum has estimated a loss of at least one hundred and fifty million cords for the province of Quebec. "The hundred and fifty million cords of pulpwood that have been destroyed by the budworm in the province of Quebec means more than fifty years' supply for our pulp and paper industry at present rate of consumption. This amount of wood manufactured into paper at to-day's price represents a loss to Canada of seven billion dollars—in fact, more than this figure, as one hundred and fifty million cords of wood make more than one hundred million tons of paper which to-day is selling at seventy dollars per ton." Mr. Barnjum's most recent estimate is two hundred million cords for Eastern Canada.

Mr. O. Schierbeck, Forester for Price Brothers, in the Barnjum prize essay, makes the same estimate. "The provincial chief forester, Mr. Piché, indicates that the Laurentian forests contain an area of about 75,000,000 acres. All these acres have been attacked by the budworm. From my knowledge of the forests of Quebec, I do not hesitate to state that 40 per cent, in all about 150,000,000 cords of this wood has been, or is under process of being killed by the budworm."

Two years ago, in 1921, Mr. Piché, Provincial Forester, estimated the loss in Quebec at 100,000,000 cords.

Loss in the Province of New Brunswick

Based on the extensive and careful crown land surveys, the extent of injury in the province of New Brunswick can be rather closely approximated. Dr. J. D. Tothill, Mr. G. H. Prince and Mr. C. S. Webb have each published estimates based on these surveys. The following quotation is from Dr. Tothill's estimate, 1921. "In the annual report of the New Brunswick Crown Lands Department for 1921 the results are given from actual tally on a 4 per cent cruise of 460 square miles (294,400 acres) of Crown lands in Northumberland county. This is the most recent survey that has been made in the area in which the budworm has run its course and the figures indicate the extent of the damage more clearly and more accurately than do those from any other survey that has been made in the province.

"As spruce and fir are the only trees injured by this insect, we need concern ourselves only with the figures for those trees. These are as follows:—

——	Merchantable sized green timber	Undersized green timber	Dead standing timber down to 6″ diameter	Acreage
Spruce........................F.B.M..	120,378,000	361,156,000	17,912,000	294,400
Fir...........................F.B.M.	86,880,000	114,067,000	258,190,000	294,000

"These figures give a loss for spruce of 60 board feet per acre and for fir of 870 board feet per acre. These figures may err slightly on the side of conservatism, particularly in the case of fir, because some of the dead trees have no doubt already become windfalls and these are not included in the tally. This error is probably counterbalanced, however, by the fact that a small percentage of the fir undoubtedly died from causes other than budworm, such as winds and fungi.

"The reconnaissance survey shows that about five million acres of New Brunswick forest lands are in about the same condition in respect to budworm injury as this block of 460 square miles. Thus, there is a loss on this area of 60 by 5,000,000 or 300,000,000 board feet of spruce, and of 870 by 5,000,000 or 4,350,000,000 board feet of fir.

"There is then an area of about a million acres in Madawaska and neighbouring parts of other counties in which the injury is very slight. The reconnaissance survey indicates no injury to spruce and a 10 per cent mortality to merchantable fir (6 inches diameter up). On an estimated stand of 1,170 million feet (the proportion of fir to spruce being smaller than in the block of 460 miles in Northumberland county) there would be 117 million board feet of dead fir.

"Finally, there is an area estimated at four million acres, chiefly in the central basin of the province, in which the reconnaissance survey indicates somewhat greater injury, especially to spruce, than in the case of the block of 460 square miles. On an estimated stand for spruce of 1,000 board feet per acre and an average spruce budworm damage of 10 per cent there is a loss here of 100 board feet per acre of four hundred million board feet for the whole area (100 by 4,000,000). The damage to fir can be estimated similarly. Allowing for the area an average board foot per acre stand of 1,000 and an average injury of 70 per cent, the damage to fir for this area of four million acres works out at 2,800,000,000 board feet.

" Totalling the results for these areas of five, one, and four million acres, respectively, we shall arrive at an estimate of the total loss to the province in board feet as a result of the spruce budworm outbreak.

Area in Acres	Loss of Spruce in Board feet	Loss of Fir in Board feet
5,000,000	300,000,000	4,350,000,000
1,000,000	....	117,000,000
4,000,000	400,000,000	2,800,000,000
	700,000,000	7,267,000,000

" Figuring the value of this lumber at the present stumpage rate on Crown lands for green timber ($4.50 per thousand for fir and $5 per thousand for spruce) the loss in stumpage value alone to the province is $3,500,000 for spruce and $32,701,500 for fir—a grand total of about $36,000,000." More recent surveys indicate that the mortality to spruce has now reached two or three times the amounts given in this table.

PART II

General Bionomics and Possibilities of Prevention and Control.

By F. C. Craighead

INTRODUCTION

One of the most striking features of the budworm injury is the great variation in different forest regions and even within circumscribed areas. Frequently an area of total destruction will be contiguous to an area where the injury is not apparent without close inspection. Observations made in one locality may apparently be flatly contradicted in another. This is, however, to be expected, for if certain types and associations were not more or less immune the wonderful coniferous forests of the past could never have existed. This feature suggested the basis from which the investigations of the budworm should be conducted. In other words, it was necessary to study the insect in its relation to the various forest environments, to determine the effects these environments had on the feeding and development of the insect; how the different species of trees as individuals or as forest types reacted to the feeding; and to try to determine the factors responsible for the death of the trees.

In presenting the following detailed discussion of various phases of this budworm problem the writer is well aware of the incomplete character of the investigations. In the first place it was impossible to study an outbreak from its beginning in any locality or on any species of tree. Furthermore, to present adequately the whole situation it would require the investigations of several specialists. Much assistance was given by various specialists, yet it was seldom possible to arrange for sufficient co-operative study in the field.

The interrelation of fungi and insects, the status of these organisms to the lowered vitality of the trees, and certain plant physiological problems proved most perplexing. There is need for much further investigation of these features which is absolutely essential to establish definitely the exact status of the insects and diseases. The discussion concerning such features is presented as purely provisional. Fully realizing his own limitations in such fields the writer finally decided, nevertheless, to describe in some detail the observation relating to these phases. The whole problem will have to be taken up again at the next opportunity and the present discussion may at least serve to call the questionable points to the attention of future investigators.

The chapter dealing with injury from the standpoint of forest types is admittedly based on insufficient data. Indeed, there are so many factors, as age, rate of growth or vigor, density and soil characteristics, influencing either the degree of defoliation or ability of the trees to recover from the effects of feeding within these types that each local variation must be considered as a unit in interpreting results.

The writer wishes to express his gratitude for the excellent spirit of co-operation shown by those with whom he came in contact and for the valuable assistance given by many. Without active co-operation of all limit holders in providing access to the forests and accommodations for travelling in the woods it would have been possible to secure information from but little of the enormous

territory invaded by this insect. The companies concerned offered every facility in furthering our studies and in enabling us to examine conditions on their limits and some made special efforts to facilitate the investigation.

The keen interest and foresighted attitude taken by Sir William Price, President of Price Brothers and Company, was much appreciated and greatly facilitated these investigations.

The entomological features of the problem are so interrelated with certain branches of forestry, as silviculture and management, and certain phases of plant physiology and mycology that the assistance of specialists in these fields greatly extended the investigations.

Mr. Otto Schierbeck, Forester of Price Brothers and Company, gave much valuable assistance by placing at the writer's disposal the results of his studies and experience in the northern woods. Mr. T. Gloerson of the same company assisted greatly in the studies of the red spruce forests on the south shore of the St. Lawrence river. Mr. R. H. Nisbit also of this company offered many facilities for study on these limits. Mr. H. R. Wickenden, Forester of the Wayagamack Company, offered many suggestions concerning the forest types in the St. Maurice valley.

Messrs. R. D. Craig, G. H. Mulloy and W. G. Wright, of the Dominion Forestry Branch, reviewed portions of the manuscript and made helpful suggestions.

Dr. J. H. Faull, of the University of Toronto, assisted in field studies of certain mycological and physiological problems and also offered suggestions in connection with the manuscript relating to these features. He called the writer's attention to root injury following defoliation.

Mr. H. T. Gussow, Dominion Botanist, Experimental Farms Branch, and Mr. W. E. Hiley, School of Forestry, Oxford University, England, aided through discussion of features relating to their specialities.

Dr. I. W. Bailey has kindly consented to discuss the microscopic abnormalities in the wood brought about by the effects of defoliation. His remarks are included as a separate chapter, with five accompanying plates.

The provincial foresters of Quebec and New Brunswick, Mr. G. C. Piche and Mr. G. H. Prince, placed at the writer's disposal much information concerning the forests in their respective areas.

Mr. J. N. Knull, Bureau of Plant Industry of Pennsylvania, spent the summer of 1922 with the Entomological Branch and assisted in observations on the life-history of the budworm and in taking plots in various forest types.

Through correspondence and interchange of visits with Mr. H. B. Peirson, State Forest Entomologist of Maine, considerable information was obtained regarding the situation in Maine and compared with conditions in Canada.

Nature of Investigations

As explained in the general introduction, circumstances prevented detailed study of the bionomics of this insect prior to the season of 1921. In the summer of 1920 through the reports of a fire ranger, Mr. Roger Gibson, it was ascertained that an extensive outbreak of the budworm had invaded the territory in the vicinity of lake Opasatika, Que., near the interprovincial boundary south of lake Abitibi. Acting on the instructions of Dr. J. M. Swaine, Mr. M. B. Dunn, of the Division of Forest Insects, went into the locality to lay out sample plots for the purpose of studying in more detail the individual trees. Two plots were laid out, each tree was numbered, and the diameter, position and general condition were recorded.

Subsequent observations on these plots were made by the writer and they furnished the basis for the greater part of the insect activities herein described pertaining to balsam and black spruce. (See footnote, page 61). They were, however, further supplemented by observations in nearby localities where active feeding was in progress and by studies in regions of older infestations where the budworm had died out from two to ten years previously. Studies of the insect's activites on red spruce were not undertaken until the following season (1922). Unfortunately it was not possible to establish sample plots in locations where the individual trees could be studied from the beginning of an outbreak. In June, 1922, a plot was selected near Bathurst, N.B. The conditions were not ideal for many features as the height of the outbreak had passed some four years previously. By means of cages in which the larvæ were concentrated and by supplementing with observations made on black spruce a fairly accurate idea of the habits was determined.

Besides these sample plot studies and field cages, numbers of caterpillars were later checked when possible in the field. Small potted trees brought into before field activities started in 1921 and 1922. These cages gave accurate data concerning the moults and much of interest concerning the larval activities which were later checked when possible in the field. Small potted trees brought into the laboratory and forced to bud prematurely furnished material on which to rear the insects.

Description of the Sample Plots

The balsam sample plots were located at lake Opasatika, Que., about midway between lake Abitibi and lake Timiskaming. This area is typical of the more northern portion of southern Laurentian forest region (Fernow). Black spruce and balsam are the characteristic conifers of this region though white spruce is frequently abundant. The white pine has largely been cut out. White birch and poplar are the characteristic hardwoods both forming mixtures or transition forests with spruce and balsam. Yellow birch occurs sparingly; no beech is found, and hard maple occurs here only as a small stunted tree.

Both plots are in mature forest, composed of pine, spruce, balsam and white birch. The last of the birch is still standing as stagheaded stubbs and the balsam and spruce have become almost entirely dominant. About five years ago the larger white pines were cut.

Plot 1 is located several hundred yards from the southern point of the lake shore. It stretches across a small depression with flowing water and is well drained. Balsam and spruce comprise the entire stand on this half acre plot. There were 137 living balsams from 3 to 12 inches in diameter and 21 black spruce from 3 to 12 inches in diameter. It comprises one-half acre. No birch occurs on this plot.

Plot 2 is located about one-half mile west of plot 1 on the top of a hill forming the higher levels. Scattered over this plot are the dying stubs of some 25 large white birch 12 to 20 inches in diameter and the stumps of some dozen white pines. There were 236 living balsams from 3 to 12 inches in diameter and four spruces. The soil is deeper and better than on plot 1. The height of the larger balsams was 65 to 70 feet. It comprises one acre.

The red spruce sample plot about 18 miles from Bathurst, N.B., was selected in a mature spruce-balsam mixture, characteristic of large areas of the Miramichi plateau. The plot is located on a large flat of deep sandy soil. Originally the stand contained many large white pines, which together with the larger spruce had been culled periodically during the past fifty to seventy-five years. Following fires, white birch made fair growth in this soil, but at present in the virgin forest these trees occur very sparingly. That the conditions were well suited to the growth of spruce is indicated by neighbouring stands on a sixty-five year burn, where many trees have attained 10 to 13 inches in diameter. The plot is slightly more than one-half acre.

History of the Balsam Sample Plots

As previously noted the first report of the outbreak centering about lake Opasatika was received in 1920. There were many lumbermen operating in this region for the preceding few years but all inquiries by Mr. Dunn and the writer failed to elicit any evidence of any previous signs of injury except from one man. Even the fire ranger, stationed here the four preceding years, who reported it, said he noticed no signs of the injury before 1920. Most reliable information was secured from an Indian, Mr. Bossom, who reported he travelled over all the region in the summer of 1919 and only saw a few tops in one locality which suggested any feeding. This feature was characteristic of the outbreak everywhere. In no case was any one found who noticed the stripped terminals the first year; in fact not until the trees began dying did the outbreaks attract attention.

The first feeding[1] on these plots occurred in 1918. It must have been quite general as the terminals of over 75 per cent of the trees examined showed retardation. In 1919, the feeding was probably severe, at least it is likely that all the new growth was consumed. In 1920, very severe feeding occurred, though somewhat differing on the two plots. On both, the entire growth of the current year was consumed and a considerable portion of the old needles. Table III gives the average amount of feeding on the old foliage by showing the number of trees grouped under each percentage class. Plot 1 was more severely stripped in 1920, 63 per cent of the old foliage being eaten while only 45 per cent was consumed on plot 2. Just the reverse occurred in 1921 on the living trees that remained. In plot 1 there was an increased feeding of only 6·6 per cent, in plot 2 of 19·1 per cent. Thus at the end of the second year on the living trees the amount of stripping was nearly balanced; 58 per cent on plot 1, 53 per cent on plot 2. In 1922, very little new growth was consumed, not enough to be noticeable on the balsam.

When Mr. Dunn laid out these plots in August, 1920, about half a dozen trees were dead on each, but it is not recorded whether they died from the effects of the budworm. The writer first visited the plots in the early spring of 1921 and recorded as dying the previous summer all trees infested by secondary insects. Later in the spring all trees dying during that winter were recorded and since then the mortality records have been grouped according to the winter and summer seasons. (See table I.) In the spring of 1923 87 per cent of the trees were dead, constituting 88 per cent of the volume.

History of the Red Spruce Sample Plot

The history of the feeding on this plot could only be determined from trees which have lived through the outbreak and by cage experiments referred to previously. In general, the feeding began in 1914 and becoming severe in 1915, continued through 1916 and 1917 and possibly 1918. It is quite likely that the 1918 feeding was not very severe, since recovering trees showed considerable growth for that season, having almost a complete set of needles, and each suc-

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[1] Explanation of defoliation: It was, of course, impossible to determine accurately the amount of defoliation each tree received. Consequently, after studying the appearance of the trees on the plots they were divided into six percentage classes. The current year's foliage was completely stripped from all trees each year and is not referred to in the percentages. One hundred per cent defoliation was applied to those trees completely stripped of all leaves. Ninety per cent indicated that a few scattered needles were present. Fifty per cent indicated a thin appearance of the foliage so that a tree behind the crown could be readily seen. Seventy-five per cent was used to indicate a stronger degree than fifty per cent but not completely stripped. On those trees recorded as twenty-five per cent defoliated some laterals were stripped though the foliage was still quite dense. Those placed in the 10 per cent class had the terminal 5 to 15 feet stripped while the remainder of the foliage was intact.

That this method of estimating the approximate amount of defoliation roughly answered the purpose intended is indicated by the tables showing correlation of defoliation by diameter classes and seasonal death—tables II and III.

cessive year's growth was longer. Since then a few caterpillars occurred each year and in 1922 they were not abundant enough to produce any defoliation that was noticeable except by careful examination. The first feeding on red spruce was evidently considerably heavier than on black spruce at lake Opasatika.

From these features it is assumed that the dying trees on the plot were probably completely stripped of all new growth during 1915 and 1916 and possibly in 1917. After 1916, practically all the old foliage would be removed from the balsam and the larvae would concentrate entirely on spruce. Only a very small portion of the old foliage of spruce was consumed.

In the spring of 1922 this plot contained:

15	living balsam, from 3 to 7 inches, d.b.h.
150	dead balsam, from 3 to 9 inches, d.b.h.
103	living spruce, from 3 to 16 inches, d.b.h.
49	dead spruce, from 3 to 17 inches, d.b.h.

The greater part of the balsam died during 1918 to 1919 and most of it had deteriorated so much that it was impossible to determine with any degree of accuracy the yearly rate of death. It was, probably, much the same as that described for the balsam plots.

Practically no spruce died before 1919, six years after the first feeding. It was possible to group the trees according to the year of death as follows:—

1919	6·5	per cent dead
1920	11·2	per cent dead
1921	14·5	per cent dead (to time of opening of the buds in 1922)
1922	26·9	per cent dead (to time of opening of the buds in 1923)

Possibly 15 per cent of the remaining living trees are beyond hope of recovery so that it can be safely predicted that the mortality of spruce will reach 75 to 85 per cent of the original stand.

SPECIAL CHARACTERISTICS OF THE BUDWORM ACTIVITIES*

Seasonal History. The activities of the overwintering larvæ begin with the opening of the balsam buds. Coincident with the bursting of these buds the general emergence of the young larvæ from the hibernacula occurs though some appear a few days earlier or later. These are second instar larvæ. Feeding begins immediately and continues through five instars for a period of from twenty-one to forty days depending on climatic conditions and the development of the current year's growth. The pupal stage extends over a period of nine to twelve days. Immediately after emerging the moths copulate and the female deposits its eggs. The flight period lasts about three weeks. Those caterpillars on white spruce mature, pupate and the moths emerge about two days earlier than those on balsam. Red spruce caterpillars pupated a few days later than balsam while on black spruce the first pupæ were seven to ten days later. The eggs hatch in from nine to twelve days. The first stage larvæ crawl about until they find a suitable place of concealment where they spin a small hibernaculum. No feeding by these caterpillars was observed. Before emerging in the spring the first moult takes place.

Food Plants and Food Preferences. Feeding habits of the larvæ have been studied on balsam, white, black and red spruce. Other food plants were observed,

*These activities refer to the balsam sample plots and to black spruce unless otherwise stated.

namely, hemlock, larch and white pine. Hemlock is fed upon quite extensively and many trees die or become stagheaded from the feeding. The larvæ can mature quite well on larch though feeding on this tree is probably never extensive. White pine is only eaten by migrating larvæ. The new growth of all trees is preferred and entirely consumed before the old foliage is eaten. Balsam is the favoured host both for ovipositing and because the larvæ can develop normally on the old foliage. The old foliage of the spruces does not support normal development of the larvæ. When they are forced to feed on old foliage, fifth and sixth stage larvæ will eat some of the needles and can mature, but the younger larvæ do not increase in size and finally die. On balsam third stage larvæ were able to feed nearly normally and mature on the old foliage though the pupæ were somewhat under size.

Adult Flight. Due to unfortunate circumstances the writer was not able to be present at lake Opasatika during the beginning of the flight of the moths in 1921. From reports from Mr. R. Gibson the moths were not nearly as numerous as the previous summer.

The first general emergence of the moths for the 1921 feeding occurred on June 26, about the time the fire weed, *Epilobium augustifolium*, is coming into full bloom. These were from white spruce and balsam.

Those feeding on black spruce emerged seven to ten days later. On July 12 the moths had all disappeared in the balsam areas (the first of the red raspberries were ripening) though many were present in the black spruce bogs and on July 28 a few adults still remained. The flight from balsam is much more regular and concentrated than from black spruce. During the height of the flight in the black spruce stands, open spaces in the woods and the roads were literally swarming with adults. A blow on the trunk of smaller trees would send hundreds from its branches.

There can be no doubt that the enormous number of moths emerging in 1920 migrated from the balsam regions due to lack of green trees on which to oviposit. Enormous flights have been reported on several occasions, particularly along large bodies of water. Many fall into the water and are washed on shore in countless numbers. It is unfortunate that no one has witnessed the beginning of such a flight.

Oviposition. No observations were possible on the oviposition of the first years but from the effects of the feeding it is quite evident that the earlier oviposition was confined almost entirely to balsam and only in 1919 were there enough eggs laid in the spruce areas to show any noticeable signs of feeding the following season.

Following the disappearance of the moths in 1921, a large number of trees were cut down in various types and counts of the egg masses made. From Mr. Dunn's reports of the abundance of eggs the previous year and the difficulty in finding them in 1921 it is probable that fewer eggs were laid. This is likewise born out by the small number of larvæ in 1922.

In the vicinity of the sample plots scarcely any egg masses were found on the heavily defoliated balsams, while the greener balsams and white spruces averaged about a dozen to a tree. On the other hand black spruce contained on an average of less than one. Here the black and white spruce were very much scattered.

In a stand of about equal proportions of black spruce and balsam, the balsam having been defoliated similarly to that on the sample plots, six trees of each species were counted. The balsam selected were the greener trees. The eggs were found in about equal numbers on each species.

In a pure black spruce stand of several square miles, that referred to in the description of the adult flight, the egg masses were found to be about one-tenth of the number of those in the mixed woods.

Spruce and balsam in mixtures with hardwoods are not selected for egg-laying unless the tops of the conifers appear above the hardwood canopy. No observations of oviposition were possible on red spruce. It was not noticed that any portion of the tree was particularly selected except that defoliated terminals were avoided.

Dr. J. D. Tothill estimates the number of eggs laid by the females to average 150.

First Activities of the Overwintering Caterpillars. The hibernating caterpillars emerge from their cocoons coincident with or a few days before the balsam buds open. They bore into the centre of the bud entering between the opening scales or directly through the base of the closed bud where contiguous buds or leaves offer a fulcrum for their bodies. (Plate XVIII, Fig. 1 and 2.) Many buds are thus destroyed before they open.

Emergence of the caterpillars from the hibernacula situated under scales of aborted balsam cones, under laboratory conditions, was as follows:—

April 25, placed in glass jars.
April 27, 28 caterpillars taken crawling up side of jar.
April 28, 47 caterpillars emerged.
April 29, 28 caterpillars emerged.
April 30, 14 caterpillars emerged.
May 1, 9 caterpillars emerged.
May 2, 5 caterpillars emerged.
May 5, 1 caterpillar emerged.
May 7, 1 caterpillar emerged.

Total 133

The emergence of these caterpillars over a period of ten days probably indicates what may be expected in the field.

Longevity of Emerging Caterpillars. To determine how long these caterpillars will live without food upon emerging from the hibernacula in the spring three lots were isolated in vials with cotton and cork stoppers and examined each day. The death rate of eighteen caterpillars was as follows:—

2nd day, none.
3rd day, 5 dead.
4th day, 4 dead.
5th day, 2 dead.
6th day, 2 dead.
7th day, 3 dead.
8th day, 1 dead.
11th day, 1 dead.

Thus on a tree containing hundreds of these hibernating caterpillars many of those first emerged would still be alive after one week, while the delayed emergence would extend the period for many by another week, with a possible maximum of twenty-one days for some few.

During the isolation of these caterpillars several moulted once.

Hibernation. The first stage caterpillars crawl about for a few days on the twigs seeking a place of concealment. As soon as suitable location is found, as under a scale of bark, in matted lichen or in an aborted cone, they begin spinning a small white silken cocoon, or hibernaculum in which they pass the remainder of the summer and winter. (Plate XVIII, Fig. 4.) Caged caterpillars did not feed before spinning up. Some moulted before, others moulted after they had spun the hibernaculum.

Later Feeding and Feeding on Balsam and Spruce Compared. (Plates VI, VII, VIII.) After entering the buds the caterpillars conceal themselves and remain concealed through all stages as long as the developing foliage permits.

As the new growth becomes from one to one and one-half inches long and the caterpillars are in the fourth and fifth stages, they begin tying the tips of several twigs together. In the later stages this nest is quite pronounced. White spruce offers much better concealment than balsam or the other spruces until the needles mature and spread, consequently the caterpillars are much more difficult to find on this tree than on balsam or the other spruces.

Later feeding is chiefly along the side of the lengthening tip. The needles are chewed off from the stem, some are eaten while many shrivel up or drop and even the soft bark is gnawed. The intensity of the feeding on the balsam, red, white and black spruce can be directly correlated with the opening of the buds and the development of the new growth. The relative opening of buds and development of new growth on these trees varies somewhat with the season, and may not harmonize with larval development, causing a variation in the amount of feeding.

An average sequence in opening of the buds and maturing of new growth is approximately as follows:—

	Balsam	White Spruce	Red Spruce	Black Spruce
Opening of buds	0	1*	10*	10*
Maturity of growth	35–40 days	25–30*	40–45*	55–60*
Length of growing period	35–40 "	25–30 days	30–35 days	45–50 days

*Days later than balsam.

The opening of the balsam buds being coincident with the emergence of the overwintering caterpillars the larvæ enter directly into these buds. The first buds attacked are soon destroyed and new ones entered.

On vigorous balsam the growth after the buds are one-quarter of an inch long is sufficiently rapid to furnish food for one caterpillar until it reaches the last moult, provided it has not before this time cut off the new growth at the base. In 1921, at lake Opasatika, the larvæ were sufficiently abundant to destroy all the new growth of balsam by the time they had reached the fifth and sixth stages, after which time they migrated about and fed on old foliage. Five to seven days' feeding occurs in the fifth and sixth stages and during this time more food is consumed than in all other stages combined.

Balsam trees that were heavily defoliated in 1920 produced a much shorter new growth in 1921. Consequently it was more quickly consumed. Fourteen days after opening of the buds on such trees the destroyed new growth had commenced to turn yellow and could be distinctly seen from the ground. Three days later about 75 per cent of the new growth was destroyed and the caterpillars were hanging by hundreds from the trees, dropping and seeking new food. None of the old foliage was eaten at this time on five trees that were cut down though two days later considerable feeding was evident. At this time last-stage larvæ were very numerous on the understory.

Referring to table II, comparing diameter classes with percentage of defoliation, it will be seen that there is a gradual diminution in feeding as the height of the trees increases. It thus happens that the understory, composed of suppressed trees, is more severely injured when the outbreak is heavy.

On more thrifty balsam, the browning of the new growth was not observed until four days later, nor did the larvæ show any tendency to drop from the trees while sufficient new food was present.

On white spruce the opening of the buds occurs about the same time as balsam and the early feeding is much the same, except due to the rapid development practically no buds are destroyed. This same rapid growth was sufficient to furnish food for all caterpillars at lake Opasatika in 1921, throughout the entire feeding period. The feeding could scarcely be noticed and very few terminal buds were destroyed on the new growth. At Bathurst, N.B., during 1922, the season was cooler and very wet, which lengthened the larval period from twenty-one days, as observed at lake Opasatika, to twenty-eight days. The new growth on white spruce hardened before the caterpillars had finished feeding, which caused a migration from these trees, and after June 20 practically none were to be found. This migration occurs about the time the needles begin to stand out at right angles to the stem, June 18 at Bathurst in 1922. Previously they are closely pressed about the axis and furnish concealment as well as large quantities of food for the larvæ.

Thus it seems that rapid development of the new growth and hardening of the needles some few days before the budworm larvæ mature are the chief factors in preventing severe defoliation to white spruce. When white spruce is severely defoliated it must occur in years of unusual abundance of the caterpillars coinciding with a season favouring rapid development of the larvæ so that maturity of the larvæ precedes hardening of the new growth.

The black spruce buds opening some ten days after the activities of the caterpillars forces these larvæ to mine into the unopened buds. A large percentage of the buds are enveloped by needles or occur in contiguous groups which gives a purchase to the caterpillars and permits easy access. The caterpillar bores to the centre of the bud and destroys the growing point so that it fails to develop. Several buds are attacked by a single caterpillar before they open. Even after the buds break the new growth develops so slowly, as compared to white spruce and balsam, that the caterpillars migrate to many buds before they have found sufficient food to complete their development. On some trees it was estimated that 25 to 50 per cent of the new growth was thus destroyed through injury to the buds before they fully opened. The larval development on black spruce is always greatly retarded, from ten to twenty days; the caterpillars are smaller in their respective stages and do not have the vigorous appearance of those on the balsam and white spruce. It is certain that this tree will not furnish food to sustain the larvæ in great numbers.

At lake Opasatika in a pure stand of black spruce general feeding began in 1919, one year later than on balsam, as indicated by ring suppression. In 1921, the feeding was quite severe, over 50 per cent of the trees had 75 to 100 per cent of the new growth stripped. Again, in 1922, the feeding was about the same though very little foliage was eaten on balsam.

Only a small percentage of the larvæ feeding in pure black spruce stands pupated in 1920. Careful search was needed to find any pupal shells, while they were very abundant on the balsam. It is thus apparent that the infestation must be renewed each year from adjacent balsam areas.

Black spruce does not produce buds as prolifically as balsam. Those contiguous to balsams and consequently severely stripped of new growth in 1919 and 1920 produced very few buds in 1921. This likewise tends to starve out the larvæ automatically in the season following heavy defoliation.

The opening of the buds of red spruce is extremely irregular as compared to black spruce. Many individual trees opened the buds about a week later than balsam, while others adjacent to these were as much as three weeks later. About ten to twelve days later can be considered as representing an average for the stand. The same early feeding and injury to the buds occurs on red spruce as described for black spruce.

After the buds open the development of the new growth is much more rapid and more luxuriant than on black spruce so that from seven to ten days later an abundant food supply is furnished. This development approximately coincides with the fourth and fifth stages of the budworm larvæ or about the time all the new growth on balsam is consumed and migration begins. Consequently, the migrating larvæ attack the succulent growth on red spruce in preference to older balsam needles. Larvæ feeding in cages showed that much of this new growth is cut off entirely and that much more is thus destroyed than is actually consumed. Thus the combined early injury to the delayed buds and the feeding by migrating larvæ explain the heavy stripping of red spruce in mixed balsam forests.

It is possible that the outbreak in these red spruce-balsam forests can become more severe and last longer than in pure balsam stands. There is a greater food supply and possibly less severe feeding on the balsam the first year.

A peculiar feature of these red spruce forests, just after the outbreak has passed, is that scattered here and there through the most severely defoliated regions are trees which have nearly a perfect crown of leaves appearing as conspicuous in the stand as the scattered white spruce. It was observed in 1922 that invariably these trees were individuals that were greatly retarded in the opening of the buds, averaging nearly four weeks later than balsam. It is just possible that on these trees the new growth was too much retarded to be greatly fed upon by the migrating larvæ and that the only injury they suffered was from buds destroyed before they opened.

Migrating Habits of the Larvæ. Several well marked migratory tendencies are shown during the larval period which play an important part in the amount of feeding both on individual trees and in various forest types.

The first stage larvæ crawl about only until they find a suitable place of concealment. Great numbers find concealment in aborted cones on the tops of the trees.

The over-wintering larvæ emerging from the hibernacula are very active and show well marked migratory activities. They are able to crawl about some few days without feeding. Opening buds are sought, but if these cannot be found closed buds are entered from some point of contact with leaves or other buds. These larvæ are capable of suspending themselves from silken threads and there is no doubt that many drift from spruces having very retarded buds in preference to boring through the closed scales. To what extent this reduces the feeding on retarded spruce could not be ascertained for in most cases sufficient larvæ bore into the buds to destroy large numbers of them. The movements of these larvæ are always upward. Large numbers of the larvæ were confined in a long glass tube. The larvæ soon collected at the upper end and on reversal of the ends immediately began climbing to the top. These tubes were held for some days, and always the upward movement continued until all the larvæ died. This feature together with the early migration explains in a large measure the concentrated feeding on the terminal. On black spruce with drooping branches more buds were destroyed at the highest point of curvature than at the pendant tip.

The remaining migrations are caused by insufficiency of food. After entering a bud and destroying it, the young larvæ crawl about until another bud is found. Although the tendency of the larvæ throughout all stages is to remain concealed, their movements in search of food are continued until fully fed. During the ultimate instar more food is consumed than in all other stages, consequently about the beginning of this period or during the penultimate instar—which in heavy infestations occurs about the time all the new growth on balsam is consumed—the migration is very marked. Countless numbers of caterpillars can be seen swinging in the air on a calm day. The threads from these suspended larvæ at lake Opasatika in 1921 matted on ones clothing while walking through the woods. On white spruce this migration occurs when the new growth becomes slightly hardened. The larvæ will not feed on old foliage as long as any new growth can be found. This migration in the later stages when all the new growth of balsam is consumed is of greatest importance in heavy outbreaks.

Results of this migration have been mentioned elsewhere, but to summarize briefly, it explains, the more severe stripping of the understory during heavy outbreaks, the absence of feeding on the old foliage of isolated balsam (drifting caterpillars cannot get back to trees) and the proportionately greater severity of stripping in purer and even aged stands of balsam; the greater part of the injury to red spruce in mixed spruce-balsam forests, the less severe stripping along the sides of roads and open places, and, partly, the immunity of white spruce. It also causes the death of great numbers of caterpillars through their inability to get back to suitable food.

Migrating caterpillars were caught on a screen 25 yards from the tree on which they were feeding.

Pupation. From three to four weeks (according to seasonal conditions) after the first activities of the larvæ, the first caterpillars pupated. Those on white spruce pupated two days earlier than those from balsam or red spruce. Pupation on black spruce occurs from seven to ten days later. Ten days after the first pupæ appear the greater part of the caterpillars on balsam, white and red spruce had pupated. On black spruce living pupæ were still found a month later.

Two or three days prior to pupation the larvæ enclose themselves in a loose cocoon of silk and leaf remains and become very quiet. The body contracts considerably and the areas between the dark dorsal bands and the mesothoracic and metathoracic segments assume a decided greenish blue tinge. The pupa is attached to the nest or twig by a few threads of silk.

BIONOMIC STATUS OF ASSOCIATED INSECTS

There are several species of bark-beetles or borers attacking living, dying or dead spruce and balsam. Some are very abundant during budworm epidemics, others entirely avoid defoliated trees but may become important following causes which destroy large quantities of timber such as blowdowns, lumbering operations or fires.

The abundance of certain species in dying trees following defoliation and the fact that some of these are capable of killing living trees makes it very essential to determine the exact status of these beetles in respect to budwormed trees.

The theory advanced for the death of trees attacked by these insects is a mechanical one. They attack gregariously, the adult beetles or the larvæ, as the case may be, bore through the outer bark to the phloeum or outer layers of wood and here extend their egg tunnels or larval mines thus girdling the trees and destroying the cambium layer. However, it is doubtful if this explains the situation in the case of *Monochamus marmorator.*

To arrive at any accurate conclusion as to the ability of these species to attack and kill healthy trees or those still having sufficient vitality to recover otherwise, it is first necessary to determine the exact conditions of host material selected by the various species and to know the history and general condition of the tree previous to attack. Observations on the sample plot trees prior to attack as well as a series of girdling experiments on spruce and balsam furnished much information. There can be no doubt that some species of these beetles are actually primary under certain conditions, yet on the other hand, very few of those attacking budwormed trees can be considered as such. There are some species which have a rather wide range of adaptability in their requirements for successfully developing a brood. On the other hand it is quite evident that many more are extremely exacting in these conditions. It is extremely interesting to note the powers of discrimination in selecting a certain log, portion of log, top or stump treated in various ways or cut at various times to the exclusion of other treatments. The moisture content of the tree or log seems to be one of the most restricting factors. There is no doubt that other factors are of much significance in respect to some species; possibly the amount and character of the reserve foods in the tree, its maturity, or the action of enzymes and micro-organisms on the dying or felled trees are of importance. It appears that there is a considerable field for investigation on this problem and until we know more about the exact requirements of these species, their ability to kill trees and their importance in relation to slash disposal cannot be definitely determined.

The moisture requirements cannot at present be expressed quantatively. On girdled trees and budwormed trees where a drying of the inner bark and outer wood is a very characteristic feature, a certain amount of experience enables one to tell by the feel of this portion of the trunk, almost exactly, when conditions are right for the attack of certain species.

It is clearly evident that trees dying from defoliation and various methods of girdling bring about conditions absolutely repellant to certain species and apparently optimum for others. On this basis the bark-beetles affecting spruce and balsam can be divided into three groups. In the accompanying list those labelled " A " have never been observed anywhere throughout the budwormed territory attacking trees dying from this cause. These are species which seem to prefer a higher moisture content of the inner bark and are capable under at least certain circumstances of killing healthy trees by gregarious attack. Those labelled " B " are very abundant on defoliated trees and all but *Pissodes dubius* are common in felled trees and slash. *Monochamus marmorator,* labelled " C," never attacks felled trees, requiring trees containing considerable moisture. It differs from group " A " in that it attacks budwormed trees.

Species	Host	Material attacked
A. *Dendroctonus piceaperda* Hopk.	Spruces	Living trees, stumps and logs.
A. *Ips borealis* Sw.	"	" tops and logs.
A. *Ips perturbatus* Eichh.	"	" "
A. *Ips chagnoni* Sw.	"	" "
A. *Ips longidens* Sw.	"	" "
C. *Monochamus marmorator* Ky.	Balsam	Living trees only.
B. *Pissodes dubius* Rand.	Balsam	Recently dead or dying trees.
B. *Pissodes rotundatus* Lec.	Spruce	" "
B. *Polygraphus rufipennis* Ky.	Spruce	Recently dead trees, logs and tops.
B. *Monochamus scutellatus* Say	Spruce and balsam	" "
B. *Serropalpus barbatus* Schall.	"	" "
B. *Tetropium cinnamopterum* Kirby	Balsam	" "
B. *Pityokteines sparsus* Lec.	"	" "
B. *Trypodendron bivittatum* Kirby	Spruce and balsam	" "

Dendroctonus piceaperda Hopk. On trees girdled and felled each month of the year, *Dendroctonus piceaperda* attacked the stumps and logs of those trees felled during the winter, the stumps of all those girdled through the sapwood throughout the entire year and the stumps of the early spring and early fall cuts of those on which a ring of bark was stripped. All the selected stumps and logs were those which were very sappy at the time of the spring flight of the beetle. In some of the stumps of the bark-stripped trees, which later during the summer dried out by evaporation through the leaves, all the brood died. Girdling experiments during an outbreak conducted by Mr. Austin Cary (Hopkins, 1901) show that this species attacks only trees girdled shortly before the flight period or in other words those that had dried out very little. Many earlier girdled trees were not attacked and the proximity to infested trees was of great importance in their selection by the beetles.

At Bathurst, N.B., in the summer of 1921, many white and red spruce were fire-scorched by brush burning, in widening a road. In 1922 all these trees were attacked by *D. piceaperda* Hopk. as well as the stump and logs of some felled trees, while nowhere throughout the entire area was this insect found in trees dying from the effects of the budworm. These trees along the road had been defoliated to a lesser degree and had practically recovered normal growth.

Ips perturbatus Eichh. In the winter of 1919 a road was cut through a certain stand of second growth spruce near lake Kenogami, Que. The following summer these logs and tops were heavily infested by *Ips perturbatus* Eichh. In 1921, the emerging broods attacked and killed some fifty spruce, 3 to 6 inches in diameter, along this roadway. Many of the trees were some 25 to 50 yards from the road, too far to be influenced by the effects of the opening. The brood emerging in 1922 failed to kill any trees.

Ips species. In the summer of 1921, the writers studied a *Dendroctonus piceaperda* outbreak in the Gaspe peninsula. This insect was attacking at the base and killing large vigorous spruces and associated with it in the tops of the same trees were *Ips borealis, perturbatus* and *chagnoni,* also *P. rufipennis.* Hopkins (1901) likewise comments on this combined attack and refers to the other species as aids in killing the trees. *P. rufipennis* apparently follows last in its attack.

Windfallen spruce throughout Quebec and New Brunswick were invariably found filled with *Dendroctonus* and these species of *Ips.*

From the foregoing evidence it seems that the necessary conditions for these species are trees which have met a rapid death and contain much moisture or living healthy trees; also that slowly dying trees, where a drying of the inner bark occurs, are not suitable.

Pissodes dubius Rand. This is the most aggressive insect of those in group "B". The puncture made by the beak of this beetle in feeding and in preparation for ovipositng or the actual placing of the eggs causes the death of a small portion of the cambium mantle around the wound. According to the vitality of the tree this may be a small oval about one-fourth inch in diameter or a more extensive area from one-half inch in width to two inches in length. It is hardly possible that the mere mechanical injury can produce this destruction of the cambian layer hence it is possible that some toxic substance is secreted during the process of puncturing the bark or in ovipositing. According to the vitality of the trees these eggs hatch or die. In case of hatching the young larvæ may extend the mines from one-half to two inches in the phlœm causing an enlargement of the dead tissue around the egg punctures. These beetles attack defoliated and dying balsam year after year but the larvæ never develop to maturity until the tree is apparently dead. In many cases the egg scars are so numerous as to destroy a large percentage of the cambium layer which is still further increased by extension of larval mines before the larvæ die. Trees recovering from the budworm feeding often show, on five or more retarded rings, the dead cambium spots produced by oviposition and in some years extension of the larval mines. Balsam trees dying in the late summer of 1922 show this unsuccessful attack for two or three successive years on the 1919 or 1920 annual ring at the base of the tree. Here for two or three years, while no wood was being formed, these insects attacked, but the larvæ did not develop. On such trees even the 1922 attack was unsuccessful, especially on the upper trunks. In no case were the larvæ able to develop until the wood surface assumed the characteristic streaked appearance indicating death.

It would thus appear that this insect requires very weakened, slowly dying trees for its attack and for the young larvæ to develop to maturity the cambium mantle must have already ceased functioning.

Pissodes rotundatus Lec. This species is confined to spruce. It is apparently somewhat less aggressive than *dubius* requiring a somewhat less sappy condition of the bark but has not been found in felled trees or logs. Spruce trees on the Bathurst sample plots dying in 1922 were attacked to a considerable extent in 1921 but the larvæ usually died before reaching maturity. Spruce girdled from September to February, 1921-22, by stripping the bark, all produced normal growth at the tip of the branches and laid on a very thin ring of wood above the girdle the following spring and summer. The roots on these trees were all dead by June, 1922, and a considerable amount of moisture lost from the trunk through the leaves. Many of the beetles attacked during May, June and July, but in no case did the larvæ live except in the September tree and in this case only after the yellowing of the cambium was recorded and over half the leaves fallen. The June and July, 1921, treatments were not attacked in 1921, but in May, 1922, this beetle attacked and the larvæ developed. Most of the leaves except last year's growth had fallen from these trees by April, 1922. This beetle did not attack trees girdled through the sapwood possibly due to the very rapid drying of the wood, nor did it attack logs nor the tops of felled trees treated at any time during the year.

At present it is not considered of any importance in hastening the death of the budwormed spruce.

Polygraphus rufipennis Ky. This scolytid has been described as causing extensive deadening of spruce. In not a single tree on which the first attack of this insect was observed was there any hesitation on the writer's part in describing the tree as dead. In fact the very decided drying of the inner bark required before the beetle attacks precludes the possibility of the tree being still alive.

Spruce trees cut and girdled each month of the year show that this beetle prefers the drying tops of trees felled or girdled at such a time that considerable moisture has been lost before the flight period in the spring. The stumps of trees girdled through the sapwood were not attacked until long after those girdled by bark stripping on the same date. In the latter case the stump dried much faster. Late winter cut logs were only attacked sometime after the first flight in the spring or frequently not at all.

Windfalls attacked by *Dendroctonus* are not infested by this species until sometime after the attack of the former when they are considerably drier. An examination of the spruce left standing after a logging operation of the winter of 1921-22 showed many trees with discoloured cambium and slightly discoloured leaves prior to the flight period of *Polygraphus*. These trees were evidently killed by exposure to excessive transpiration after logging while the ground was still frozen. Later in the spring these trees were attacked by *Polygraphus* but no trees that opened buds that spring were attacked.

On budworm killed spruce dying eight years after the outbreak, in no case was attack observed before practically all the old needles had fallen from the trees. These trees failed to open the buds that spring or if attacked later in the summer withering of the new growth preceded attack.

Monochamus scutellatus Say. This Cerambycid has always been regarded as attacking only dead trees, as fire-killed timber, windfalls or felled trees. The conditions required differ little from that of *Polygraphus* except that logs are attacked sooner after felling and dead budwormed spruce some days or weeks prior to the attack of the barkbeetle.

Tetropium cinnamopterum Ky. The exact status of this species is doubtful and may be of more importance than it is here considered. It requires conditions similar to *Monochamus scutellatus,* though it has been frequently observed attacking much earlier. Hopkins (1901) considered it as important in conjunction with *Dendroctonus* attack. A western species, *T. abietis,* is reported killing living firs.

Pityokteines sparsus Lec. The conditions required by this bark-beetle in balsam are similar to those of *Polygraphus rufipennis* in spruce, though possibly preferring slightly less dried material. The larger balsams dying during the winter are selected by the numerous spring brood. Smaller trees dying in the winter which dry out quickly are never attacked. During the summer no trees are attacked until after the current year's needles have started to wither and the cambium is quite streaked and discolored. It can in no sense be considered as primary.

Trypodendron bivittatum Ky. This ambrosia beetle is only mentioned because of its abundance. The character of its mines (boring straight through the bark into the wood) preclude any possibility of this insect killing trees. It is the earliest of these insects to fly in the spring and attacks the base of all trees dying during the winter, previous to the attack of any of the others. The work is easily recognized by the powdered white frass and affords a ready means of " spotting " winter killed trees.

Serropalpus barbatus Schall. This Melandryid is likewise mentioned merely because of its abundance. It attacks the lower trunks of trees having the same condition attractive to *Monochamus scutellatus* and living trees where it can gain access to the sapwood through a blaze. The larvæ feed in the sapwood mining very little beneath the bark.

All evidence seems to indicate that the species grouped under " B " can successfully attack only after the cambium mantle has ceased to function; and that they require a certain reduction in the normal amount of moisture present in the trees.

Monochamus marmorator Ky. This Longicorn is perhaps the only one of the species of beetles attacking budwormed trees that can be regarded as primary, i.e., capable of killing the trees. It is not of so much importance during the outbreak (see page 49) as it is some two to five years after the defoliators have disappeared. There is much evidence to indicate that it prevents the recovery of a large percentage of the trees in some localities that would otherwise live after defoliation.

On the balsam sample plots egg scars of this species were observed on a great many trees the summer preceding their death. The larvæ in practically all cases succeeded in developing, though it is unlikely that this would have been the case were the trees not so much reduced in vitality.

In the summer of 1921, a dying balsam was found in the woodlot of the Forest Insect Field Station at Aylmer, Que., containing larvæ of this species. Examination of the woodlot showed some fifty dead balsams from 4 to 15 inches in diameter which had died during the past five years and all with the characteristic pitch flow, produced on the bark by this species. On July 6, six living balsam in this woodlot were numbered; the only remaining trees found over five inches in diameter. These trees, from all appearance of foliage, were in good condition. They were growing on good soil and previously had made very rapid growth. Tree No. 3 had a small patch of dead bark near the base in and around which *marmorator* larvæ, from last year's eggs, were boring. Tree No. 5 had two roots dead on the south side. These trees, also Nos. 1 and 4, showed numerous egg scars of the previous year, but in all cases, except as noted on tree No. 3 and possibly No. 6, the young larvæ died before boring through the bark. On July 10 the first eggs were laid on these trees and by August 15 all were very heavily attacked except tree No. 2 which contained only a few eggs. A copious pitch flow exuded from all the scars. None of these trees had been previously attacked by the budworm.

The further history of the trees is as follows:—

Tree No. 5, age 46 years, D.B.H. 8 inches; September 20 a few larvæ were under the bark, but nearly all overwintered in the inner bark. A slight off colour of the foliage was noted by October 1 and was recorded "tree apparently beginning to die but not enough girdling to kill it mechanically." By November 1 a discoloration of the inner bark was noted in spots and more decided change in the foliage especially on tips of twigs. May 1 a more decided colour change of the foliage had taken place in the top half of the trees but the lower portion had made no further change. All this time the larger roots were green except one which was dying. The rootlets on other roots were apparently in good condition. The larvæ were mining under the bark for the entire length of the trunk. Two weeks later than normal the buds opened on the lower few whorls of branches while those on the remainder of the tree were dormant. Very many male flowers were produced and some cones which only developed to about one-third normal size. The new growth on these lower branches did not exceed one-half inch in length. June 6 *Pissodes dubius* was observed ovipositing. On July 1 the foliage on the top half of the tree was decidedly yellowish-brown while the lower whorls were less coloured. The wood surface was still normal in appearance at the collar above some of the greener roots though the small rootlets were dead and more of the main roots. August 6 the foliage on top had reached the maximum colour phase of a dead tree, the new growth on the lower branches was withering, the wood surface was entirely brown and *Armillaria* was noted on several roots. In September the tree was cut and the annual rings studied. For the past four years gradual and decided reduction was shown. In 1921, a very thin layer was added over the entire tree and in 1922 only a narrow strip on one side of the tree near the branches which opened buds.

Tree No. 6, age 45 years, D.B.H. 6 inches. This tree differed from No. 5 in its more rapid death. In late September many larvæ were mining under the bark; *Pissodes dubius* had attacked and some larvæ were living; the leaves were yellowing and the cambium was decidedly discolored. By April, 1922, all leaves were reddish-brown having reached the maximum colour change. There was a similar reduction in annual layers of wood of the past few years and only a thin layer was added on the basal portion of the stem in 1921.

Tree No. 4, D.B.H. 11 inches. The 1921 ovipositing was not so heavy as on tree No. 5 and all larvæ died except a very few which continued working in the bast the following spring. May 1 all roots were alive and a very heavy crop of male flowers was forming. The buds on the lower half of the tree opened ten days later than normal and those on the top half three weeks later than normal. The new growth on the lower branches was not over one inch long while that on the top half did not exceed one-fourth to one-half inch. June 6 no discoloration of the cambium on roots or stem was noted. A month later a slight yellowish discoloration of top foliage was noted, and some rootlets were dead on the tip of one root examined. There were a considerable number of eggs laid on this tree in the summer of 1922. This tree will probably repeat the history of No. 5 next season. Increment borer cores on lower trunk showed the same reduction in annual wood for the past few years.

Tree No. 3, age 70 years, D.B.H. 11 inches. The history of this tree is practically identical with that of No. 6. No *Armillaria* was noted.

Tree No. 1, age 56 years, D.B.H. 12 inches. Most of the 1921 larvæ overwintered in the bast and nothing abnormal was noted until April when the foliage over the entire tree was slightly discolored, though the cambium was normal. May 1 the cambium on two roots was brown and discoloring on another, the larvæ were mining under the bark and discoloration of the cambium was noted in places. The buds started to swell but never opened. By June 1 the cambium on all roots and the stem was decidedly discolored, except on one root. By July 6 the foliage was brick red on the middle and upper parts of the tree and by another month over the entire tree. The same gradual reduction of rings since 1918 was noted. *Marmorator* larvæ were only abundant on the basal six feet of the trunk and no other insects (*Pissodes* or *Pityokteines*) attacked it until June, 1922.

Tree No. 2, D.B.H. 10 inches. None of the larvæ lived in 1921. Some further oviposition occurred in 1922 but these eggs or larvæ all died. The tree is normal in all appearances though a slight decrease in wood at the base is noted for the last three years and again this year.

If these trees have been killed by the attack of *M. marmorator,* and it seems logical, for the present, to draw that conclusion, they certainly have not been killed by the mechanical girdling of the larvæ. Oviposition of this insect occurred on all the trees dying this year for at least three or four years previously and on two trees, Nos. 3 and 5, old scars were found in the wood back to 1915. In each case the eggs or young larvæ from the earlier attack died except a few on tree No. 3 from the 1920 ovipositing and a few in tree No. 4 from 1921, so these larvæ certainly could not develop until the vitality of the tree was very low. The reduction in the annual rings is of quite a different character from that of defoliated trees. These trees seem to die from the top down, failing to add wood on the terminal portion a year or two before death. Those dying after a budworm attack fail to form wood at the base of the tree before death.

OBSERVATIONS RELATING TO THE DEATH OF THE TREES

The determination of the actual factors involved in the death of the trees following defoliation, should make possible more effective remedial measures. If defoliation alone kills the trees all efforts in prevention must be directed against the primary insect; if the secondary bark-beetles and borers are largely responsible, destruction of these insects would materially assist in reducing total losses; if the previous vitality of the tree alters its resistance to the effects of defoliation then measures to secure optimum growth and vigor are in order.

Harper (1913) in describing the suppression in the annual rings of larch, produced by feeding of the larch sawfly, describes the death of the trees as a starvation phenomenon. That this does not entirely explain the present situation is evident from observations described in the following pages. The writer in a preliminary statement (1922) wrongly attributed the death of the trees largely to the attack of secondary insects and diseases, and felt that without these agencies large numbers of trees would recover from the effects of defoliation. Observations on deciduous trees defoliated by the gypsy moth in the New England States have shown that many species live through repeated complete defoliations. These trees, however, invariably put out a second crop of leaves, which the balsam and spruce fail to do. Defoliation of larch by the sawfly extends over a longer term of years and is more gradual than in the case of the budworm; the larch also puts out a second crop of leaves. Briefly, the situation, in the case of balsam and spruce, may be described as death due to the failure of certain physiological functions following defoliation.

Hartig (1892) in a very interesting and detailed report of the feeding of the nun-moth on spruce shows that one complete defoliation kills the trees. He studied the effects of defoliation on the reserve foods, chiefly starch, the moisture content of the wood and on the temperature of the trunks, emphasizing particularly the effects of increased temperature, following the opening, in destroying the cambium.

Description of the Dying Trees

On the balsam sample plots the first feeding occurred in 1918 and the first trees died in the summer of 1920. Since then, the dying trees have been tabulated just as the buds opened in the spring and after all insect activity ceased in the fall. Thus the dying trees have been grouped by summer and winter seasons. The history of the mortality on the balsam sample plots is shown in table 1.

TABLE I.—Tabulation of Sample Plot Data of Dying Balsam on Balsam Plots I and II

Time of Death	Number Trees	Per cent Trees	Per cent Volume	Average Diameter	Average Defoliation	Average Radial Increment for 10 years preceding attack in mm.	Average Age
Summer, 1920	33	8·9	9·3	5·9	77	8·5	63
Winter, 1920–1921	74	19·8	11·7	4·8	81	10·5	58
Summer, 1921	45	12·1	12·3	5·7	70	10·9	60
Winter, 1921–1922	52	14	16·6	6·7	62	11·7	65
Summer, 1922	55	14·5	19·5	6·9	57	14	70
Winter, 1922–1923	63	17·4	18·7	6·1	46	15·4	65
Total	322	86·7	88·1				

TABLE II.—Correlation between Defoliation and Height*

D.B.H., inches	2	3	4	5	6	7	8	9	10	11	12
Number of trees	4	47	65	31	57	54	44	30	19	11	11
Average defoliation, per cent	54	77	66	64	51	46	42	29	28	28	14

*As indicated by diameter.

It is clearly evident that the causes bringing about the death of trees dying at different periods during and after the budworm outbreak are not the same.

Following the defoliation, the first indication of lowered vitality is the reduction in the current year's wood on the terminal portion of the trees. (See detailed discussion, page 51.) The second or the third season following severe defoliation, the tree may fail to add an annual ring at the base and in some trees as much as three years' wood is lacking on the lower trunk before the tree dies.

Shortly following defoliation, at least on balsam, the absorbing rootlets begin to die.[1] (Plate VI, figure 3.) This was a very characteristic feature of the balsam at Lake Opasitika in 1921 following the severe feeding of 1919 and 1920. The number of dead rootlets bears a very marked correlation to the severity of defoliation. An examination of the rootlets of young balsams was made in late August, 1922, comparing normal trees with those that were severely frosted June 14. On the frosted trees all the new growth was destroyed. Slight though unmistakable injury to the small rootlets of the frosted trees was evident. This dying of the rootlets occurs one or two years before the death of the tree. On red spruce the dying of these rootlets is a much more gradual process. On many trees examined six months preceding their death all the rootlets below the diameter of two millimeters were dead and completely rotted. Following this condition in balsam the trees were not checked off as dead until a characteristic streaking of the cambium appeared and a slight yellowing of the older needles. In the case of spruce the same streaked appearance of the cambium was noted and also a shedding of the older needles which fall without changing colour. Spruce trees, at Bathurst, N.B., following the disappearance of the caterpillars in 1918, added four years of new growth. Trees dying during the summer of 1922 had already shed all needles except

[1] Dr. J. H. Faull first called my attention to this condition which he investigated in connection with a needle blight of pine.

the 1920 and 1921 growth, and in some cases many of the 1920 needles were gone. The previous year's growth (1921) was, however, confined to relatively few branches, which in many cases was an abnormally long slender spur. (Plate VIII, figure 1.) Those trees both spruce and balsam on which the buds opened much later and less vigorously than normal almost invariably died during the summer. In 1921, the buds on all living balsams on the sample plots were recorded, one week after normal opening, as good or poor. Of the total number dying that season practically all were trees recorded as having poor bud development.

The foregoing discussion relates particularly to trees dying during and shortly following the outbreak. Some six to ten years after the outbreak many of the remaining trees continue to die. These trees have all regained a full complement of foliage and appear quite normal. In the case of balsam they may have also developed one to several new terminals. However, many have never recovered normal growth as shown by the thickness of the annual rings.

These trees die more slowly than those succumbing during the outbreak. They frequently die gradually from the top, a little more each year for about three years, before the entire tree is killed.

Mr. W. E. Hiley, School of Forestry, Oxford, Eng., made an extensive study of these trees during the early summer of 1922. He came to the conclusion that the trees were dying from lack of sufficiently large rings to transport the required amount of water to the crown. *Monochamus marmorator*, accelerates the death of such trees (see pages 49, 86).

Defoliation

The death of both spruce and balsam bears a direct correlation to the severity of defoliation. This is well illustrated on balsam by the table of percentages of defoliation for the sample plots at lake Opasatika (Table III). Thus after the 1920 feeding 100 per cent of the totally defoliated trees died, and 98·5 per cent of those denuded of 90 per cent of their foliage died. Following the 1921 feeding all the 90 and 100 per cent defoliated trees died. Of the remaining trees the percentage of death decreases at a fairly regular ratio with decrease in defoliation to those receiving 25 per cent defoliation, which show a death rate of 28 per cent at the end of the summer of 1922. No trees receiving less than 25 per cent defoliation have died up to the present.

TABLE III.—Correlation between Defoliation and Death

Per cent of Defoliation	Number of trees in each class after 1920 feeding	Per cent dead at end of 1920	Number of trees in each class after 1921 feeding	Per cent dead at end of 1922
100	21	100	0	
90	40	89	18	100
75	63	46	75	82
50	124	17	118	56
25	88	8	51	28
10	37	0	0	0

TABLE IV.—Radial Increment in Millimeters for Ten Years Preceding Defoliation compared with Seasonal Death

Trees dying	Summer 1920	Winter 1920-21	Summer 1921	Winter 1921-22	Summer 1922
Rate of growth (all trees)...	8·5	10·5	10·9	11·7	14
Rate of growth (trees 75 per cent defoliated).	9·2	8·6	11·4	10·4	13·1

It was impossible to make definite studies as to the amount of foliage consumed on individual red spruce trees. However, the appearance of trees in 1922 at Bathurst is definitely convincing that those now recovering were least defoliated during the outbreak. Practically all of these trees which are recovering show at least some new growth remaining from each year of the attack.

Water Supply

A certain correlation seems to exist between the abundance of available water and the recovery of the trees following defoliation. On the balsam sample plots many of the remaining living trees are grouped in a shallow depression. In plot No. 1, lake Opasatika, this depression carries water throughout the season, while in plot No. 2, running water is only present in the spring and early summer. Near these plots is a small tongue of land about two feet above the lake level, projecting out into the lake. This is covered with balsam trees which are still alive and stand out in sharp contrast to the complete destruction all around.

In running strip surveys through badly infested country there was invariably a higher percentage of living spruce and balsam in depressions or along streams. A comparison of plots Nos. 17a and 17b taken not 50 yards apart illustrate the effect of moisture. The low mortality of plot No. 1, Bathurst, is in part due to this fact. When first considering the variation in injury the character of the soil was thought to be a prominent feature, but it is now believed that the importance of soil variation lies chiefly in its water retaining capacity. On thin shallow soils, gravelly or sandy soils, the percentage of death is always higher.

The season of 1921, which was an extremely dry one, was probably responsible for the death of at least 15 per cent of the total number of spruce dying on the Miramichi plateau in New Brunswick. A study of the rings shows that many of these trees had started to recover in 1920 but died following the dry season of 1921.

Winter Killing

The high mortality during the winter from the beginning of the outbreak certainly bears some relation to the effect of low temperatures. During the winter of 1920 and 1921 a total of 21 per cent of the trees died on the balsam plots. In the winter of 1921 and 1922, 14.1 per cent of the trees died. Thus of the 70 per cent mortality to date 35 per cent took place during the winter. These are chiefly suppressed trees and those of less vigour as indicated by yearly increment of those receiving 75 per cent defoliation. Tables I and IV show the average diameter and rate of growth of these trees as compared to those dying during the summer season.

Hedlund (1912) has shown that the ability of plants to withstand freezing depends in a large measure on the concentration of the cell sap. "The storing up of soluble as well as insoluble substances in the cells during the summer is consequently an active means of protecting the protoplasm against damage by freezing." Trees, defoliated of all new growth and much of the old foliage for two or three seasons, can manufacture but very little new food, and consequently would have but little reserve food with which to resist the rigours of the following winter.

Maturity and Vitality

Considering individual trees on the sample plots the thickness of annual rings was used as an indication of the vitality of the trees. Tables I and IV show the average width of ten rings preceding first feeding in 1918 of all trees dying from the summer of 1920 to that of 1923, also the same data for all trees receiving 75 per cent defoliation. A gradual increase is shown from that group dying first to that dying last. The vigour of the stand at the time of the budworm attack largely determines the condition in which it will come through.

The highest percentage of dying trees is found in overmature or virgin forests. This is well illustrated by red spruce on the Miramichi plateau. The second growth where the old Miramichi fire occurred stands out in much better condition than the mature forest adjacent to it (compare plots Nos. 3 and 15). In the country north of the Saguenay river large areas were burned over about eighty years ago. The balsam on this old burn along the Shipshaw river suffered to the extent of 10 to 15 per cent while in adjacent virgin forests the merchantable balsam was entirely destroyed.

Observations on Girdled Trees

In April, 1921, a series of coniferous and hardwood trees were felled, girdled through the bark and girdled through the sapwood. These cuttings were continued each month for one year. The object of these experiments was to check the life-histories of the insects attacking the trees, to determine the optimum conditions for insect attack, to check the discoloration of cambium and leaves after death and to compare the death of these trees with those dying from budworm attack.

From the standpoint of the budworm, those trees which were killed by stripping off a ring of bark about one foot wide, three feet above the ground proved of most interest. Balsam, white spruce and cedar *(Thuja occidentalis)* were used, but balsam was treated for only six months.

All the cedars had branches to the ground, below the point of cutting or girdling. In no case did these stumps die from any of the treatments. The same applied to balsam in some few trees which had branches below the point of treatment; in all other balsam and all spruce (these had all lost lower branches) the stumps and roots died. A large percentage of the roots died in all treatments.

The September bark stripped balsam was of particular interest. It had three whorls of branches below the girdle. No changes were noted in discoloration of leaves or cambium before April 21 of the following spring at which time the cambium was slightly discoloured and drying, and later the leaves above the girdle assumed a light yellowish tinge. The buds on branches below the girdle opened normally. A month later an examination of the roots showed that many of the rootlets were dead. During the summer the lower branches produced about two inches of new growth and by fall these branches appeared quite healthy though over 75 per cent of the roots were dead and rotted. The other balsams responded as the girdled spruce except that the needles did not fall but remained on the trees for an entire year after changing colour.

The spruce treated in April and May, 1921, opened their buds, put on new growth normally and added a thin layer of wood above the girdle. Those treated from May 15 through to August 15, had already started or finished new growth before girdling and failed to open the buds the following spring. Those treated from September to February all put on new growth to 1922 which was quite normal in all respects. A thin layer of wood was added above the girdle. In no case was wood added below the girdle. The rootlets of all trees girdled through the early summer began to die within a short time and the cambium on the stump darkened very quickly. On those trees which were treated after the summer activities ceased the rootlets begun to show abnormal conditions shortly after the buds opened in 1922 and by July were entirely dead to the thickness of 2 to 3 millimeters. The leaves fell gradually beginning with the older needles and about this time the cambium above the girdle showed a slight discoloration and dryness. Previously the needles had assumed a slightly pale green shade and fell in this condition. No insect attack was successful above the girdle until after the cambium had discolored.

There seems to be a parallel between the death of these trees and those dying from budworm defoliation. In these girdled trees death is quite rapid as compared with that of the budwormed trees.

Secondary Insects

The attack of the secondary insects appeared at first to be of much importance in the death of the defoliated trees. After following the condition of many individually numbered trees prior to death it became quite evident that they were in reality of little significance, except *Monochamus marmorator,* five to ten years after defoliation. In the foregoing pages the condition of the host preferred by the various species is considered.

Packard (1890) was first of the opinion that barkbeetles and borers were mainly responsible for the death of the budwormed trees but later statements suggest that he attributed less importance to them. He says: " We are now inclined to the opinion, then, that the "Bud Tortrix" is the sole or at least the main cause of the destruction of spruces and firs in Cumberland, Sagadahoc and Lincoln Counties, Me., and by their attacks they render the trees liable to invasion by a host of barkbeetles."

None of the numbered trees dying during or a few years following the defoliation were recorded as successfully attacked by insects when they did not show unmistakable evidences of death previously. The most important requisite of the insects concerned seems to be the moisture content of the inner bark and wood. After some experience it was possible to tell, by the feel of the wood surface, when moisture conditions were about right for the attack of certain species. In all trees death of the rootlets, shedding or discoloration of the older foliage, a streaking or browning of the cambium, and absence of one to three layers of wood at various parts of the trunk had preceded insect attack. It is hardly conceivable that these trees would have recovered.

Again, many trees (about 30 per cent) die without being attacked by secondary insects. This is particularly true of those dying during the winter. By spring the inner bark of these trees dries out to such an extent that the insects prefer the more favourable condition of those more recently dead. Larger winter-killed trees with heavier bark are usually attacked in the spring. As previously mentioned, in trees dying some years after the outbreak—those which have regained normal foliage—*Monochamus marmorator* is apparently of more importance.

An examination on April 20, 1923, of the spruce sample plots at Bathurst, N.B., showed that 26.9 per cent of the trees had died since June, 1922. About one-fourth of these died during the July and August of 1922; the remainder died during the late fall and winter and on the above date all showed browning of the still unhardened 1922 needles, discoloration and drying of the cambium and bast. None of the trees contained any bark-beetles or borers, since the flight of these had not yet begun. Ambrosia beetles were attacking the lower trunks. Some few contained scattered larvæ of *Pissodes rotundatus* Lec. but only one tree had sufficient numbers to suggest that this insect might have played a part in killing the tree.

The Shoe String Fungus

The shoe string fungus, *Armillaria mellea,* is very prevalent throughout the budwormed area. Practically every dead balsam is attacked by this fungus either at the time the tree was recorded dead or shortly after. *Armillaria* showing about the juncture of the roots and stem, at the time of death was much less prevalent on trees dying early in the outbreak than on those dying later. Thus of forty trees dying in the winter of 1920-21 only four showed the mycelium in the late spring; of fifty-two dying in the winter of 1921-22, twenty-one showed the mycelium and of fifty-five dying in the summer of 1922, forty-three were infected. On many of these the mycelium had practically girdled the base before insects attacked the trees. It was almost invariably associated with discoloration of the foliage and the cambium. The mycelium gained entrance at the tips of the dead rootlets and worked rapidly up the roots to the butt of the stem on dying trees. On two trees which are still alive the mycelium was recorded on the ends of roots in the late summer of 1921 and has not made any further progress.

It has been very difficult to determine the degree of parasitism of this fungus, since it is necessary to disturb the tree greatly to find it in its incipient stages. In some half dozen cases, trees were completely girdled at the base while the cambium was not sufficiently discolored to record as dead. The increase in its prevalence on trees dying in 1922 may possibly be explained by the more extensive dying of the roots at this time.

In those areas where the budworm attack appeared some ten years ago it is likewise very prevalent on all dying trees. It can, as well, be found on dead roots of living trees and at the point where the dead root joins the living tissue two or three layers of wood may cover the edge of the mycelium sheet indicating no recent progress of the disease. It is much less prevalent on spruce and in fact was rarely found until after the trees had been dead one year.

Taking all observed facts into consideration it seems more reasonable to assume that this fungus is merely a very abundant and active saprophyte in the present circumstances.

Characteristics Associated with the Death of the Trees

It was found necessary to use some standard to designate death of the trees, as early as possible, in order to record the insect activities in relation to the death of the trees. Just when to record these trees as dead proved a very perplexing problem. Since trees felled at certain times in the spring open the buds and even partially unfold some leaves, and since the discoloration of the foliage takes place very slowly under certain conditions, neither of these features could be utilized. It was found that by felling or girdling, the first indication observable to the eye was a slight streaky discoloration of the cambium[1].

Although in many cases trees dying from defoliation were no doubt unable to respond to normal stimuli some time before this condition of the cambium was noticeable, it was found to be the best criterion for field use. In no case was this discoloration noted, except in the vicinity of wounds, unless a few days

[1] Dr. I. W. Bailey has since called my attention to the fact that this streaked appearance is due to the loss of water from the tracheides and its replacement by air.

later a decided browning of the inner bark surface had taken place, followed later by discoloration of the foliage. Although the cambium layer had ceased to function in the formation of wood for two or three years prior to the death of the trees, no discoloration took place until shortly before other signs of disintegration were apparent.

Discoloration of the Foliage

The colour-changes and shedding of the foliage of dead spruce and balsam are quite useful in determining the approximate length of time the tree has been dead, when the previous history is not known.

Balsam foliage, shortly following the death of the tree, loses the natural lustre of living trees and assumes a faint yellowish tinge which gradually deepens from yellow to bright reddish-brown in the course of four to ten weeks, depending on the season and the method of killing. In felled trees or those ring-girdled through the sapwood during the summer the foliage assumes the red-brown colour in one month's time, while those treated in the winter turn the following spring. Those dying without any interruption of the active wood between the crown and roots change colour very slowly. On standing trees which died in the winter months the older foliage begins falling late in the summer, but much hangs on until the next spring. Occasionally, some remain throughout the summer. These trees can be distinguished, however, by the dull brown as contrasted with the bright brown foliage of trees dying later.

Spruce foliage never assumes a very decided colour change. Shortly after the tree dies the needles loose their gloss which, however, is rather difficult to distinguish except by contrast with healthy trees. At the same time the older needles begin to fall and are often practically all shed within three or four months. The new growth assumes a more contrasting colour and is the last to fall. The new growth of trees dying before the leaves mature assumes a reddish brown colour. This is quite noticeable on some trees killed by *Dendroctonus* and *Ips*.

RETARDATION OF THE ANNUAL RINGS[1]

Plates I to V

A very characteristic feature of the budworm outbreak is the reduction in growth of the annual rings laid on during and for several years following the outbreak. The discussion of this feature and the figures here given are not complete in some respects since in no place has the outbreak been located in its early stages and proper material correlated with defoliation was not secured for the first trees dying. Likewise it was impossible to check first retardation with first feeding, but it is assumed that the first year of terminal reduction corresponds with the beginning of the outbreak.[2] Judging by the history of the balsam plots, balsam trees recovering from the outbreak would be those that had received about 25 per cent or less defoliation of the old needles and which had had all the new growth consumed for two or three years. On red spruce no definite estimate can be given; however, since only the new growth is con-

[1]Unfortunately at the time the sections were taken from these trees the importance of the exact position in relation to the height and crown development was not realized. All trees were growing under forest conditions. The basal sections were always taken above the root swelling between thirty and forty inches above the ground. The middle section was taken below the crown on the clear bowl at the middle of the total height. The top section was cut below the killed terminal averaging about four feet from the tip where the diameter ranged from one to two inches though rarely reaching the latter. The object was merely to determine a typical pattern of ring suppression that could be applied to all regions to determine the year of the budworm epidemic. The other features discussed are incidental developments.

[2]Hartig, 1892, describes artificial defoliation experiments on spruce and pine stating that the wood was greatly reduced the same year the foliage was removed. He also notes the reduction of wood the first year of defoliation by nun-moth.

A small balsam, enclosed in a wire cage, defoliated by the budworm larvae of all new growth in 1922 laid on an abnormally narrow ring that summer.

sumed and since many of these trees die it is probable that those recovering did not receive complete stripping of the new growth, or only for one or two years at the most.

Recovering Trees

The annual ring formed during the first year of attack, on both spruce and balsam which recover, is very characteristic, showing sudden severe reduction in the top of the tree decreasing in intensity toward the middle to a point where it is not noticeable, followed by a gradual increase in thickness of the ring further down and becoming quite decided near the base.[1]

The terminal retardation shows to best advantage a few whorls below the point where the terminal was killed. There is also often little or no summer wood formed in this portion the first year. These features apply to both red spruce and balsam though in spruce the decrease in terminal growth and increase in basal growth are less marked. Frequently in regions where the percentage of balsam greatly predominates or in large blocks of nearly pure black spruce the first affected ring in spruce is one year later than in balsam. Red spruce is affected the same year as balsam.

In general, the decrease in the thickness and recovery of rings, in spruce and balsam which lived through the outbreak, follow much the same curve. By comparison of Figs. A and B, it will be seen that during the first year of feeding the line representing terminal growth falls below both that of the middle and the base; some little decrease in the middle and an increase in the basal portions takes place. The growth on the terminal shows a slight recovery a year or two following the first depression or before final recovery. In balsam, the first depression covers a two-year period and is much more marked than in spruce, corresponding to the heavier defoliation. The second depression may be due to the prolific production of cones immediately after feeding stops. The line representing the increment of the middle sections in both cases falls below the basal and then crossing above it continues in an intermediate position. In both spruce and balsam the greatest reduction in the terminal and basal sections takes place the same year; in spruce four years after the first feeding, in balsam five. It is quite common to find almost total suppression of rings on the lower trunk of balsam. Occasionally as much as three years are lacking on some portions of the trunk. In no cases in spruce that recovered from an outbreak were annual rings found to be missing. Final recovery, to normal growth preceding the outbreak, requires from twelve to fifteen years. The spruce curve was based on fourteen trees all from the same locality and the depression in the last year corresponds to the abnormally dry season of 1921. The balsam curve is based on thirteen trees from widely separated areas.[2] The accompanying tables give the average measurements from which the curves were plotted and typical individual trees. (Tables V, VI, VII, and VIII.)

Dying Trees

Harper (1911) has very carefully described the effects of the defoliation of the larch sawfly on the growth and structure of wood of the European larch. His discussion applies to dying and dead trees and his results pertaining to the loss of summer wood and reduction in increment agree very well with that observed for spruce and balsam. However, these trees differ in two features from his description of larch. The first year of feeding the basal sections show increased growth on spruce and balsam which is not mentioned for larch. He also uses the first year showing absence of summer wood as a method of correlating the same year throughout the stem, assuming it to be the first year of

[1] This basal thickening was at first considered as possibly due to climatic effects, the defoliation having occurred in a year of heavy precipitation. It was later checked in balsam from widely separated localities where the first feeding took place in 1910, 1911, 1913, 1914 and 1918. At three localities precipitation records were available and in two cases the first feeding occurred in a year of lower precipitation than normal.

[2] Since these figures were tabulated they have been verified by measurements on over 2,000 trees.

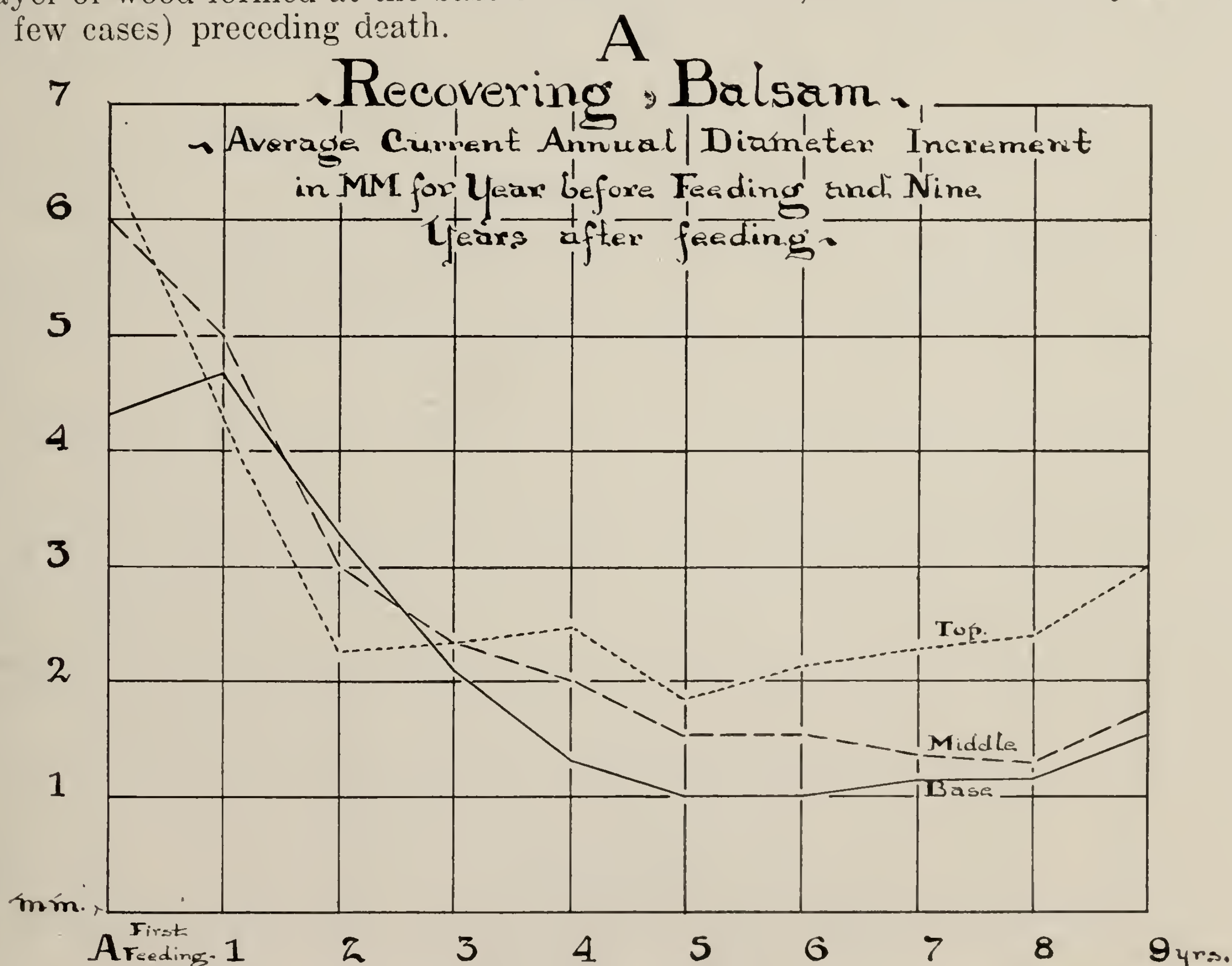
feeding.[1] In spruce and balsam absence of summer wood at the base is rarely shown until two years after its absence in the top.

Basal sections for the dying balsam (see table VII and fig. E) were obtained for trees dying since 1920, on the balsam plots. A comparison of these data show that the trees dying earlier in the outbreak made no increased growth in 1918 the first year of feeding, and greater reduction in wood in 1919 and 1920. This corresponds to the severity of feeding (compare table I), also these were trees of less vigour, as shown by the rate of growth (table I) for ten years previous to the outbreak.

In the balsam dying later, during the summer 1922, (see table VII and fig. D) the first year of feeding shows the terminal decrease and basal increase similar to the recovering trees. During the following years all sections show decreasing amounts of wood laid on and no recovery. The basal increment after the first year falls off more sharply and later fails entirely three years after the first feeding. The middle portion of the tree may lack one or two years usually only one while the terminal in most cases puts on some wood the summer preceding death or even the same summer if dying late in the growing season.

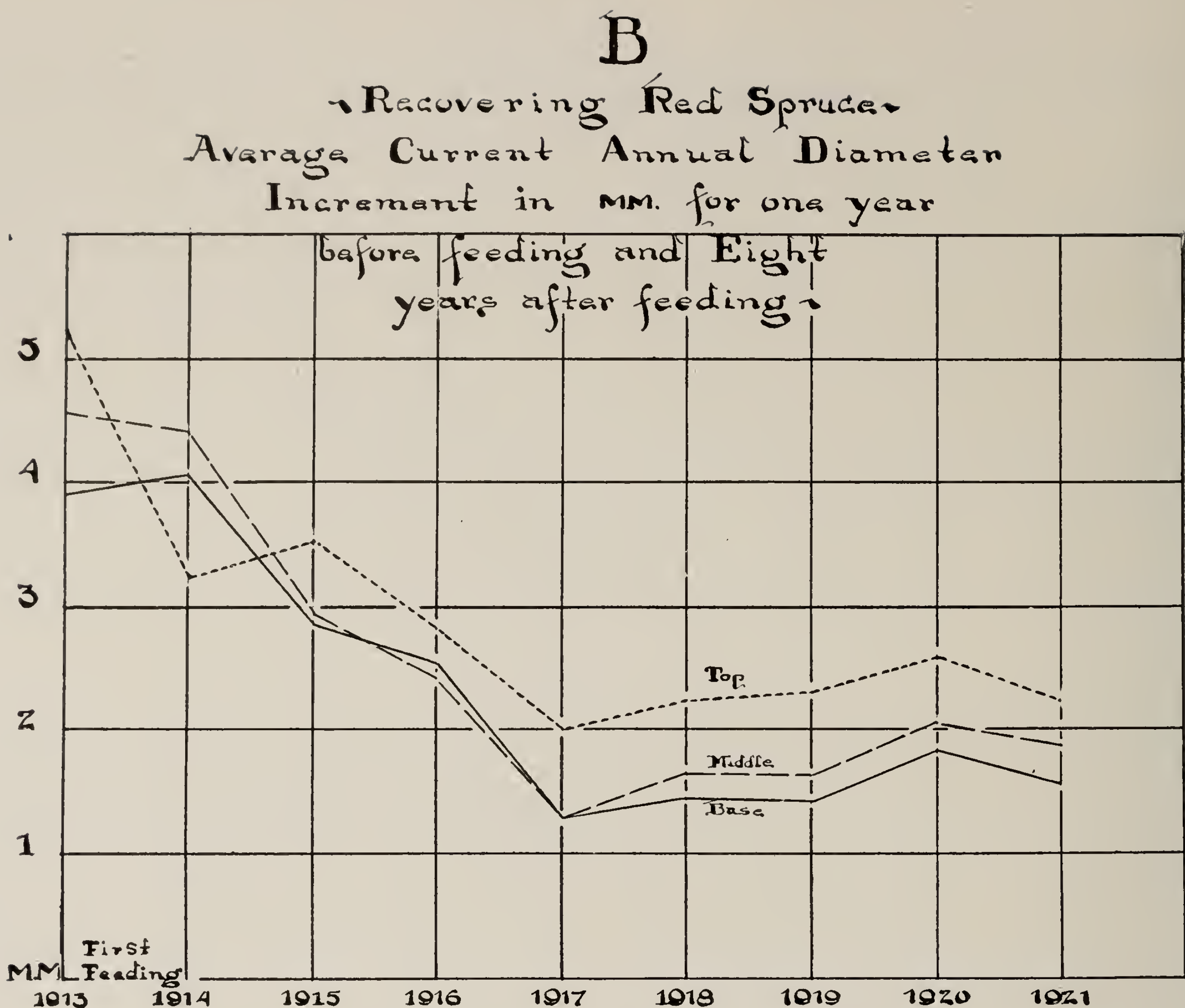
The reduction of the annual rings of spruce was not studied in the first trees to die following the outbreak. Table VIII and fig. C shows effects produced in trees dying during the winter of 1921-22. Similar terminal reduction and basal increase occurs but in the following years the reduction is much more gradual and not until seven or eight years after the first feeding is wood lacking at the base. All the trees failed to put on wood at the base in 1921.

Thus the most characteristic feature of the dying trees is the absence of a layer of wood formed at the base of the tree for one, two or even three years (in a few cases) preceding death.

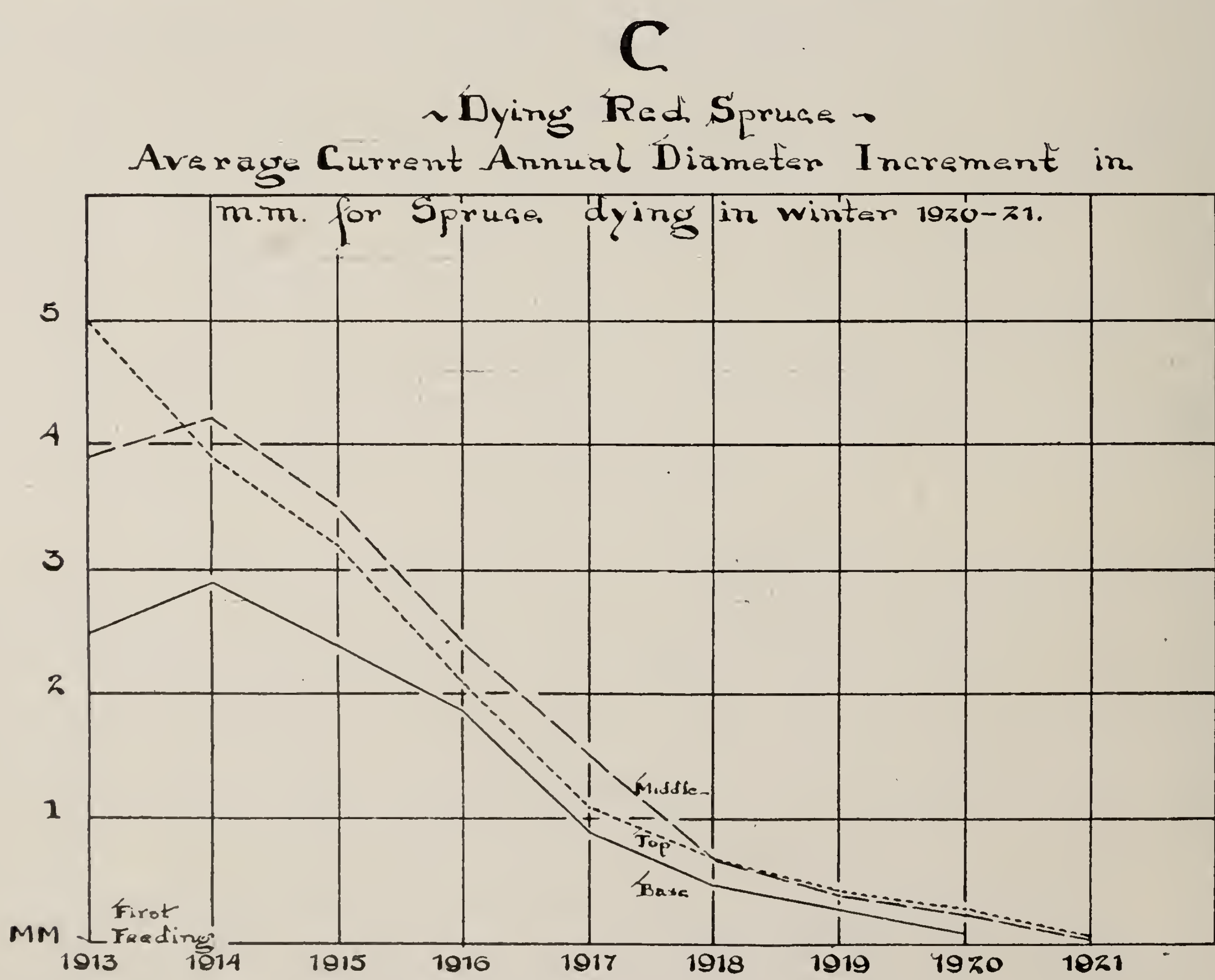


(For balsam that recovered 1, 2, 3, etc., refer to years after first feeding.)

[1]The method used by the writer was that of cross identification described by Douglas. It was found to be easily applied to trees growing close together, such as on a single sample plot, but was difficult or impossible of application for this purpose, to trees on different sites or localities. Also on the numbered sample plot trees a small piece of bark was removed at the time the plot was laid out,

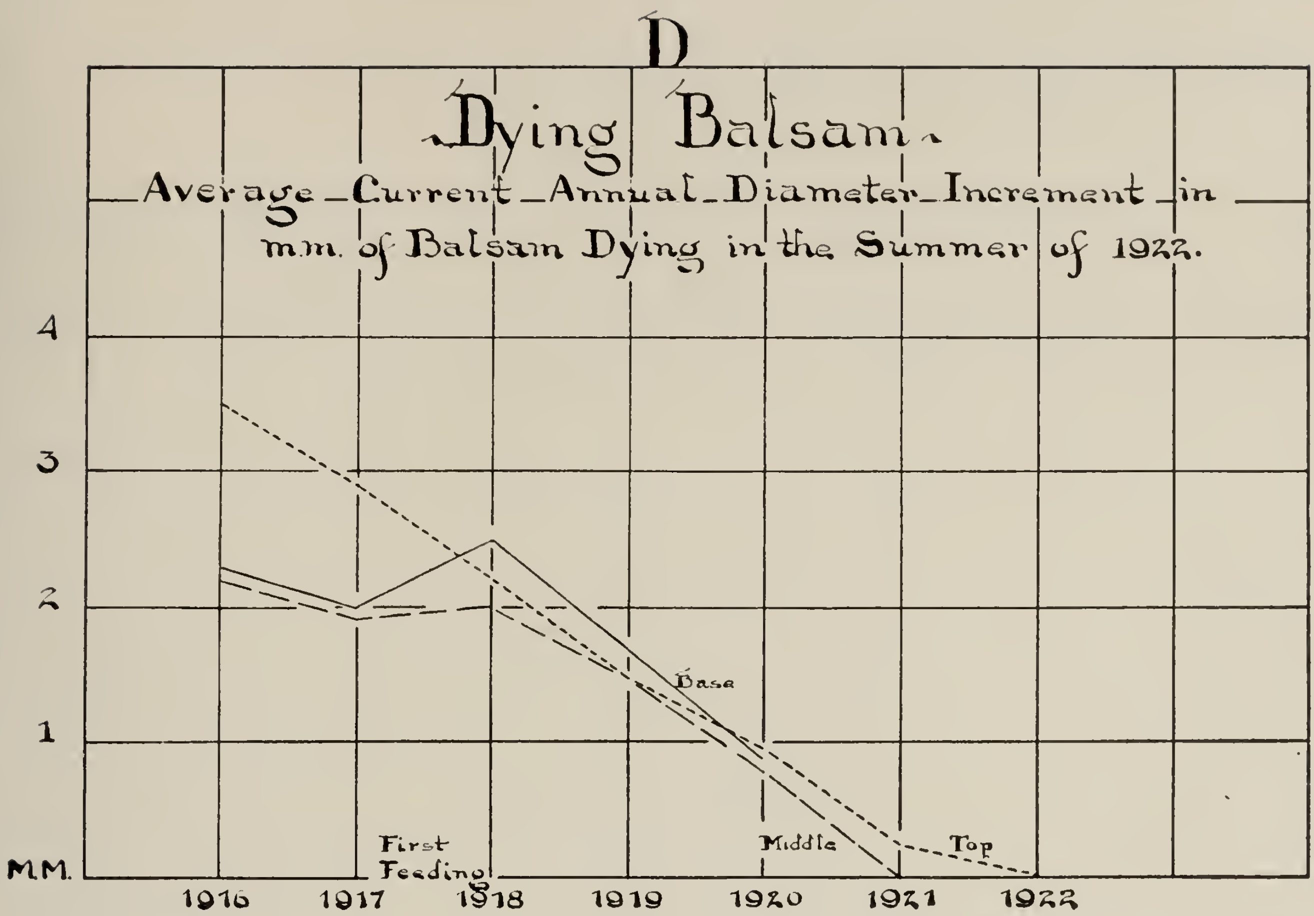


B
Recovering Red Spruce
Average Current Annual Diameter Increment in MM. for one year before feeding and Eight years after feeding
5
4
3
2
1
MM
First Feeding
Top
Middle
Base
1913
1914
1915
1916
1917
1918
1919
1920
1921

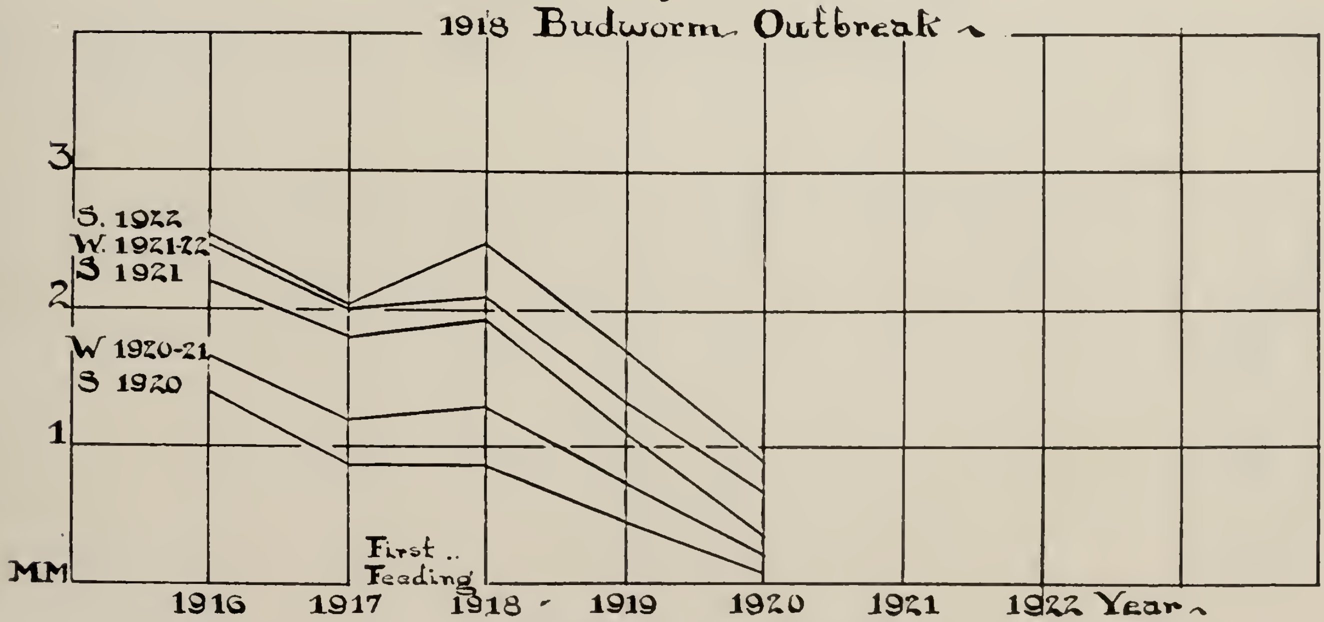


C
Dying Red Spruce
Average Current Annual Diameter Increment in m.m. for Spruce dying in winter 1920-21.
5
4
3
2
1
MM
First Feeding
Middle
Top
Base
1913
1914
1915
1916
1917
1918
1919
1920
1921

D



E



S—summer; W—winter.

TABLE V.—Retardation of the annual rings of living balsam showing average width of rings in millimeters for one year preceding the first feeding and for nine years following. Based on thirteen trees cut August and September, 1921 at widely separated localities where first feeding began in 1910, 1911, 1913, 1914 and 1918.

Section	Year Before Feeding	First Year Feeding	Second	Third	Fourth	Fifth	Sixth	Seventh	Eighth	Ninth
Top.............	3·29	2·11	1·12	1·17	1·24	0·91	1·08	1·14	1·20	1·52
Middle...........	3·02	2·54	1·51	1·19	1·04	0·79	0·78	0·69	0·65	0·88
Base.............	2·15	2·34	1·63	1·05	0·65	0·51	0·53	0·58	0·59	0·78

MEASUREMENTS OF RINGS OF INDIVIDUAL TREES IN TENTHS OF MILLIMETERS.

Fief St. Claire, Que., First Feeding 1911

No.	Section	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920
1	Top.....................	40	20	12	10	7	5	3	2	2	5	5
	Middle..................	28	25	13	13	6	4	4	2	2	4	5
	Base....................	25	28	17	12	2	5	3	2	5	12	19
2	Top.....................	35	22	14	5	4	6	8	2	17	17	21
	Middle..................	32	30	20	12	5	3	3	(½)	1½	13	25
	Base.........	25	21	20	15	4	3	(1)	(1)	(2)	5	21

Flamand, Que., First Feeding 1910

No.	Section	1909	1910	1911	1912	1913	1914	1915	1916	1917	1918
2	Top...........	42	18	15	6	15	18	20	18	19	23
	Middle........................	40	38	28	12	12	10	8	11	13	12
	Base..........................	24	27	22	13	7	4	3	5	6	7

( ) Annual ring not formed completely around tree.

TABLE VI.—Retardation of the annual rings of living red spruce showing average width of rings in millimeters one year preceding the first feeding and for eight years following. Bathurst, N.B. First feeding 1914. Based on fourteen trees cut July 1922.

	Diameter	Height	1913	1914	1915	1916	1917	1918	1919	1920	1921
Top....................	1·6 inch	29 feet	2·61	1·62	1·78	1·42	1·00	1·13	1·16	1·30	1·12
Middle................	3·6 "	17·8 "	2·29	2·20	1·47	1·22	0·66	0·82	0·82	1·03	0·94
Base....................	5·1 "	2·8 "	1·97	2·02	1·46	1·28	0·66	0·72	0·71	0·92	0·79

MEASUREMENTS OF RINGS OF INDIVIDUAL TREES IN TENTHS OF MILLIMETERS

No.	Section	1913	1914	1915	1916	1917	1918	1919	1920	1921
16	Top..............................	28	15	15	16	10	9	9	11	8
	Middle...........................	22	20	17	11	4	3	2	4	3
	Base.............................	22	24	19	14	4	3	3	4	3
17	Top..............................	28	15	19	17	14	11	14	11	9
	Middle...........................	21	22	19	12	8	6	7	7	6
	Base.............................	20	24	20	15	8	5	6	5	5
5	Top..............................	33	20	13	18	8	10	8	12	8
	Middle...........................	25	22	12	10	6	10	7	8	6
	Base.............................	31	30	20	20	9	14	11	15	8
12	Top..............................	24	11	9	6	4	5	7	12	12
	Middle...........................	17	17	12	8	5	9	12	20	16
	Base.............................	18	18	15	10	8	9	12	19	19

The summer of 1921 was unusually dry.

TABLE VII.—Retardation of the annual rings of balsam dying from the summer of 1920 to that of 1922 showing average width of rings in millimeters for two years preceding first feeding until death. Basal sections approximately three feet above ground. Based on over 150 trees on balsam sample plots, Lake Opasatika, Que.

	1916	1917	1918	1919	1920	1921	1922	
Trees dying summer 1920	0·7	0·45	0·45	0·23	0·07	0	0	Base
Trees dying winter 1920–21	0·83	0·70	0·75	0·39	0·12	0	0	"
Trees dying summer 1921	1·1	0·9	0·98	0·55	0·19	0	0	"
Trees dying winter 1921–22	1·17	1·0	1·05	0·64	0·35	0	0	"
Trees dying summer 1922	1·17	1·0	1·26	0·84	0·46	0	0	"
Trees dying summer 1922	1·10	1·44	1·03	0·73	0·43	0·04	0	Middle
Trees dying summer 1922	1·73	1·45	1·1	0·73	0·47	0·12	0·01	Top

MEASUREMENTS OF RINGS OF INDIVIDUAL TREES IN TENTHS OF MILLIMETERS DYING THE SUMMER 1922.

No.	Section	1916	1917	1918	1919	1920	1921	1922
	Top	30	22	12	7	5	2	1
141	Middle	15	15	13	11	6	2	0
	Base	11	12	17	11	7	0	0
20	Top	17	17	8	7	5	1	0
	Middle	8	8	9	6	4	0	0
	Base	9	8	10	6	4	0	0
4	Top	26	26	17	8	6	1	0
	Middle	9	9	13	7	5	0	0
	Base	5	5	13	10	5	0	0

TABLE VIII.—Retardation of the annual rings of red spruce dying in winter 1921–22, showing average width of rings in millimeters for one year preceding first feeding until death. Based on twelve trees cut July 1922, Bathurst, N.B.

Section	Diameter of Section	Height of Section	1913	1914	1915	1916	1917	1918	1919	1920	1921
Top	1·5 inch	28 feet	2·5	1·97	1·60	1·07	0·57	0·36	0·22	0·16	0·04
Middle	3·3 "	17·1 "	1·97	2·10	1·74	1·24	0·76	0·36	0·21	0·13	0·01
Base	4·5 "	3 "	1·25	1·44	1·21	0·96	0·45	0·24	0·14	0·05	0·00

MEASUREMENTS OF RINGS OF INDIVIDUAL TREES IN TENTHS OF MILLIMETERS.

No.	Section	1913	1914	1915	1916	1917	1918	1919	1920	1921
9	Base	22	23	20	17	6	4	3	(1)	0
	Middle	26	28	25	18	15	5	4	3	1
	Top	30	18	20	11	7	5	3	1	½
12	Base	14	18	15	13	5	2	(1)	0	0
	Middle	30	28	23	16	7	3	2	0	0
	Top	29	25	20	15	5	6	2	2	1
3	Base	12	14	15	13	4	2	(1)	(1)	0
	Middle	29	28	22	20	8	4	1	1	0
	Top	30	25	20	15	8	4	1	1	(1)

( ) Annual ring not formed completely around the trees.

ABNORMALITIES OF RING GROWTH AND CELL STRUCTURE

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In studying the effects of budworm defoliation upon the formation of annual rings in spruce and balsam, Dr. Craighead encountered a number of apparent abnormalties, *i.e.* zones of discolouration, false rings, defects resulting from the feeding of *Pissodes dubius,* absence of wood formation during certain growing seasons, etc., which appeared to be more or less closely associated with the attacks of the budworm. It occurred to Dr. Craighead that microscopic investigations might prove to be of considerable value in interpreting the significance of the structural peculiarities, as well as in verifying conclusions based upon macroscopic analyses. Accordingly, sections of typical stems from various localities in Quebec and New Brunswick were sent to the writer for microscopic examination; together with as many detailed descriptions of the trees, and of their life histories, as possible.

Sections of balsams from the St. Claire, Saguenay and Long Lake[1] sample plots proved to be particularly interesting from the histological, as well as from the general biological, point of view. The photomicrographs in the accompanying plates illustrate certain of their salient structural features. Figs. 1 to 3 are transverse sections of the wood from the upper, median and basal portions of the stem of balsam No. 2, Fief St. Claire, P.Q., a tree which recovered from the attacks of the budworm. The sequence of rings in the upper disk—the thirteen outermost of which are shown in fig. 1—is (1) a narrow ring next to the pith, (2) a group of three very wide rings, (3) two somewhat narrower rings (labelled 5 and 6), (4) a group of six conspicuously narrow rings (labelled 7 to 12), and (5) an outer group of four wide rings. The three innermost layers are dark, reddish brown, as is also the succeeding ring which has a narrow, yellowish, " corky " zone close to its inner margin. The fifth and sixth layers are characterized by having narrow, dark, reddish-brown zones, the former in its central portion and the latter upon its outer margin. In view of the fact that the first feeding of the budworm in the St. Claire locality is known to have occurred in 1911, a macroscopic examination of this specimen indicates that the reduction in cambial activity during the formation of the fifth to the twelfth growth layers was in all probability due to budworm defoliation. It is essential, however, to determine (1) whether the apparent discolourations actually are concomitants of the attacks of the insects and (2) whether the sixth growth layer is a complete ring or a false ring. If it is a false ring, the fourth growth layer must have been formed during the first year of defoliation.

As shown in figs. 1 and 12, the " corky " zone near the inner margin of the fourth ring is a layer of crushed and distorted tissue. Such injuries are not produced by mere defoliation, but are typical of the effects of a late frost upon immature cells formed during the earlier part of a growing season. That this type of abnormality is not produced by budworm defoliation is indicated, furthermore, by the fact that it is of common occurrence in rings which were laid down many years before the first feeding of the insects. The dark, reddish-brown colour of the four innermost rings is not produced by chemical discolouration or the deposition of material subsequent to the attacks of the budworm or the death of the terminal shoot. On the contrary, it is due to the presence of specialized cells, fig. 9, which normally begin to secrete " resinous " substances soon after their differentiation from the cambium. Although these " resin cells "

[1] Long Lake and Lake Opasatika are the same.

frequently are very numerous in the three or four innermost rings of the stems of balsam, they normally become evanescent in succeeding growth layers and usually are absent in the later formed rings. It is significant, however, that under unusual or abnormal conditions of growth, they may again become abundant in the outer rings. Under such circumstances, they tend to be aggregated in more or less sharply defined and comparatively narrow zones, and may give the impression of false rings in macroscopic analyses. In the specimen under discussion, the zonal distribution of resin cells in the fifth and sixth rings, and the reduced width of these growth layers, suggest some nutritional disturbance. As shown in fig. 10, there is a narrower layer of "summerwood" upon the outer margin of the sixth ring, but its presence is obscured in macroscopic analyses by the dark, reddish-brown zone of resinous tissue. The structure of the upper portions of the stems of other balsams from the St. Claire locality strongly supports the conclusion that the fifth ring in fig. 1 was formed during the first year of budworm feeding (1911), and that the wide fourth ring was laid on during 1910. Fig. 4 shows a very marked reduction in cambial activity during the 1911 growing season, and the distribution of resin cells is strikingly zonal. Under higher magnification, fig. 14, the outer zone of resinous tissue is seen to contain resin cysts, structures which are formed in the wood of balsam only as a result of injury or abnormal conditions of growth. Thus, the microscopic structure of the St. Claire specimens supports Dr. Craighead's generalization that in the apical portions of the stems of balsam there is a conspicuous reduction in cambial activity during the first year of the feeding of the budworm.

The sequence of rings in the median, fig. 2, and basal, fig. 3, disks of balsam No. 2 is in general similar to that in the apical, fig. 1, portion of the stem, but with the following exceptions. The 1913-1919 growth layers are much narrower and one or more of them are omitted; one ring is missing in the median section, figs. 2 and 8, and as many as three growth layers in certain radii of the basal disk, figs. 3, 5, and 6. Furthermore, the three outermost increments of wood, formed during the period of recovery, are considerably wider. It should be noted, in addition, that zones of resin cells and resin cysts are not present in the outer growth layers of the median and basal disks. There are, however, in the basal section, more or less isolated, short arcs of resin cysts in certain portions of the circumference of the 1919 ring, figs. 3 and 5. These aggregations of secretory reservoirs resemble the traumatic tissue produced by *Pissodes dubius* in balsams which have been enfeebled by attacks of the budworm. The excavations of the beetles and the feeding of the larvæ stimulate the surrounding areas of the cambium and lead to the formation of resin cysts, fig. 7. It seems probable, therefore, that balsam No. 2 was attacked by beetles during the 1919 growing season, before the tree had fully recovered from the effects of budworm defoliation.

It is of interest to compare disks from the St. Claire trees with those taken from Saguenay balsams, since in both of these widely separated localities the first feeding of the budworm occurred in 1911. In the apical portions of both sets of stems, there is a late frost injury near the inner margin of the relatively wide 1910 ring, which is succeeded by two narrower layers having an abnormal development of resinous tissue. Fig. 11 is a transverse section of the wood of the upper portion of the stem of a Saguenay balsam, No. VI-28. The outer zone of resin cells and resin cysts gives the impression of a false ring near the inner margin of a wide growth layer. That this resinous tissue actually was formed at the end of the 1912 growing season, is indicated in fig. 17, a transverse section of homologous growth layers of a disk which was cut 15 feet lower in the stem. The resin cysts in the 1912 ring subtend a narrow zone of "summerwood," as does the zonal aggregation of resin cells in the 1911 growth layer. Although the structural peculiarities of the 1910-1912 rings of balsams No. 2 and No. VI-28 are very similar, the Saguenay specimen shows a rapid recovery during the period (1913-1918) when the St. Claire balsam was forming its narrowest rings. Such discrepancies may very well be due to different intensities and durations of feeding, as well as to differences in the vigour, age and general growth conditions of the trees.

Figs. 15, 16 and 17 illustrate transverse sections of the wood from the upper, median and basal portions of the stem of balsam No. 86, Long Lake, P.Q., a tree which died during the late summer of 1922, four years after the first feeding of the budworm. The activity of the cambium during the first year of feeding was curtailed in the upper part of the stem of this tree, but was considerably accelerated in its basal portion; a phenomenon which Dr. Craighead finds to be a common concomitant of certain intensities of defoliation. The zone of wood formed during 1918 may be distinguished by its relatively greater width in the median, fig. 16, and basal, fig. 17, disks, but there is some difficulty in locating it in the apical section. As shown in fig. 15, there is a wide ring succeeded by what appears macroscopically to be four narrower growth layers. Under higher magnification an inner zone of cambial activity is clearly visible in certain arcs of the very narrow outer ring. Is this more or less evanescent layer a false ring or is it tissue which was laid on during the 1921 growing season? In other words, was the wide growth layer in fig. 15 formed during 1916 or 1917? It is possible to answer this question by cross-identification of rings in the three disks, as the 1913-1917 zones of wood are distinguished by very constant and characteristic differences in their relative widths. The wide ring in fig. 15 is the homologue of the 1916 ring in figs. 16 and 17. Thus, it is evident that, in the upper portion of the stem, there was a very marked curtailment of cambial activity during the first year of feeding (1918), and that little or no wood was laid on during the 1921 growing season. It should be noted, in this connection, that one entire ring is omitted from the median disk, fig. 16, and that both the 1921 and 1922 growth layers are missing from the basal section, fig. 17.

Fig. 18 is a transverse section of the wood from the upper portion of the stem of another balsam, No. 7, from the Long Lake locality. This tree also died during the late summer of 1922, four years after the first feeding of the budworm. The sequence of growth layers is very similar to that shown in fig. 15, but the 1921 ring is much wider. Furthermore, there is a late frost injury near the inner margin of the 1918 ring, and there is a zone of traumatic resin cells at the junction of the 1920 and 1921 growth layers, fig. 22. Fig. 19 is a transverse section of the same stem, cut at a somewhat higher level. The relative widths of the rings are approximately the same as in fig. 18, but the resinous tissue is more abundant. As shown in fig. 20, there are narrow zones of resin cells in the 1918 and 1919 growth layers, and traumatic resin cysts near the outer margin of the 1920 ring, fig. 23. The abundance of resinous tissue in the apical portions of the stem of this tree, and of balsam No. 4, fig. 21, raised the question whether the apparent absence of such tissue in figs. 15 to 17 might not be due to the fact that the disks were cut at too low a level in the stem. Fortunately, Dr. Craighead was able to send the writer the uppermost section of balsam No. 86. In this portion of the stem, fig. 24, there are numerous traumatic resin cysts and resin cells upon the outer margins of the 1919 and 1920 growth layers, and the 1921 ring is much wider than in the disk illustrated in fig. 15.

In summarizing the results of the writer's microscopic investigations, it should be emphasized that given intensities and durations of budworm feeding may produce strikingly different effects in different parts of the stem of any particular tree. This is conspicously the case in the production of zonal aggregations of resin cells and resin cysts. Such abnormalities are formed apparently only by those portions of the cambium which are in relatively close proximity to the pith. Therefore, during the period of their formation, they are confined to young, slender, apical portions of the stem. The feeding of *Pissodes dubius,* on the other hand, may lead to the production of short arcs of traumatic resinous tissue in the older, more robust, median and basal portions of the stem.

In macroscopic analyses, it is essential to distinguish zonal abnormalities produced by budworm defoliation from late frost injuries which tend to have a similar distribution. Fortunately, the latter abnormalities have a characteristic yellowish colour, and a " corky " texture, and are easily recognizable under a hand lens. They should prove to be of considerable assistance in dating annual rings in regions where reliable meteorological records are available.

BUDWORM INJURY CONSIDERED BY FOREST TYPES

The great variation in feeding by the budworm and subsequent injury in different permanent forest types, transitional types, quality sites and age classes is of direct importance in formulating plans for future management of the forests. Considerable difficulty was experienced in accurately limiting and defining the various forest types encountered. Discussion with foresters of these regions and a review of the literature have convinced the writer that further investigation is needed on this subject. It is absolutely essential to differentiate accurately these various types to discuss adequately the budworm injury or formulate any suggestions on forest management. The distinction between red[1] and black spruce and various races of these trees is likewise essential.

Fernow (1908) divides the eastern Canadian forests into six regions which he designates as the Upper, Middle and Lower St. Lawrence, the Northern or Subarctic, the Southern Laurentian, and the Acadian.

The Upper, Middle and Lower St. Lawrence are practically non-existent as forest lands to-day, having been almost entirely occupied by farms. Many small stands of second growth pure white spruce, from thirty to seventy-five years of age, exist on old clearings or abandoned farms. A few of these have been studied but in no case have the trees been killed. Retarded increment for a few years and destroyed terminals are the only results of the epidemic. The isolated character of these forests prevented serious injury.

The Northern or Subarctic region occupying the northern slope of the Laurentian plateau or north of the height of land in Quebec is little known even to-day. No reports of budworm injury have been received and we may well surmise that there has been none, since the general type is described as a spruce forest, white and black spruce being by far the predominant species. Piché (1922) says " white and black spruces form here very dense stands bearing from seven to forty cords per acre; but owing to the waste caused by muskegs and water the average volume of the forest tract is rather low, running from three to seven cords per acre." These forests are supposed to exist chiefly along the streams.

The Southern Laurentian comprises practically all of Quebec between the height of land and the plains of the Ottawa and St. Lawrence rivers on the south, also extending westward into Ontario. In this region characterized by

[1]The distinction between red spruce, *Picea rubens*, and black spruce, *P. mariana*, has been the centre of much discussion. The writer encountered the same difficulties in separating these trees but has tentatively adopted the following: The spruce occurring south of the St. Lawrence river in the Acadian region is considered as a distinct race or possibly species, red spruce; that north of the St. Lawrence in the Laurentian region as black spruce. Both occur in several distinct types and approach each other in form and growth. This distinction is based on the effects of the budworm feeding and on the development of the current year's growth. The spruce in the Acadian region has suffered severely from budworm injury in all types. The spruce of the Laurentian region has been practically immune in all types. In the former the current year's growth develops and matures much faster after the buds open and is much more bulky than in the latter (see page 35).

Archean rocks, exist very diversified forests composed mainly of white, red and jack pine, black and white spruce, balsam, white and yellow birch, beech, maple and poplar. In Quebec, much of the white pine and larger spruce has been removed for saw timber while the present cuttings are chiefly spruce and balsam for pulpwood.

The Acadian Region, quoting Fernow (1908), "comprises the Maritime Provinces, with the Eastern Townships of Quebec south of the St. Lawrence river added. This area, being geologically a continuation of the Appalachians, the forest represents the same type as the Maine or northern New England type, a birch-maple-beach hardwood base with coniferous mixture, which on the higher slopes and plateaus may become pure. Originally white pine, at present white and red spruce with balsam fir, form the valuable part of the composition." Red spruce is at present the most characteristic softwood of this region.

For the purpose of the present discussion only the Laurentian and Acadian regions need be considered. Certain of the forest types occurring in these regions are similar, at least in respect to the effects from the budworm, while others are quite different and are considered separately. The types to be discussed are as follows:

1. Northern Hardwood Type, Laurentian and Acadian.
2. (Black) Spruce Swamp Type, Laurentian.
3. (Red) Spruce Swamp Type, Acadian.
4. Spruce Slope Type, Laurentian and Acadian.
5. Black Spruce Flat Type, Laurentian.
6. Red Spruce Flat Type, Acadian.
7. Birch-Poplar Type, Laurentian } Transitional Types.
8. Birch-Poplar Type, Acadian }
9. White Spruce Stands, Laurentian and Acadian.

Balsam occurs in several other types where it is of little commercial importance. In cedar flats considerable balsam and some spruce frequently occur. Relatively little injury has been noted in this type, possibly due to the scattered occurrence of the balsam and the abundant moisture supply. Zon (1904) describes balsam in the fir slope type. This type was observed in a few places and invariably suffered almost complete destruction. On the headwaters of the Metis river in Quebec where the budworm feeding was very light, scarcely effecting any other types, 75 per cent of the balsam was killed in the dense balsam stands on the hilltops. The slow growth of these trees and the susceptibility of the situation to desiccation in dry seasons probably made the trees very susceptible to feeding.

Local Distribution of Injury

The first impression of the budworm injury in a circumscribed area leads one to believe that elevation plays an important part in the severity of feeding, or in other words the injury appears to be worse, and frequently is, in the valleys. This has been explained as due to the flight of the moths, drifting with air currents, up or down valleys, the higher ground acting as barriers. Generally speaking the percentage of conifers is greater on lower ground while hardwoods predominate at higher elevations, thus giving more favourable conditions for feeding at lower elevations. Coniferous types existing above the hardwood belt, when containing much balsam, are very severely injured. On the Northwest Miramichi river in New Brunswick the mortality averaged 10

[1]The type classification here adopted follows that of the Research Committee of the Society of American Foresters, as provisionally proposed in the Journ. For. Vol. 20, No. 2, February, 1922. A distinction is made between the types of spruce occurring in the Laurentian and Acadian regions due to the reasons given in a previous footnote. In this discussion red spruce always refers to the tree occurring in the Acadian region.

per cent higher on the uplands. At Metis, Que. (where the epidemic was very light) balsam on the hilltops was almost completely wiped out while in the lowlands only 10 to 15 per cent was killed. A patchy distribution of mortality is characteristic of the area. Numerous other examples could be cited to show that the character of the forest and distribution of types are of much more importance than elevation.

Northern Hardwood Type

This type, characterized by sugar maple, beech and yellow birch, occurs usually on higher ground on deeper, better soils. It is abundant and well distributed in New Brunswick; in Quebec it extends north, to lake Kippewa in the west, and to near lake Kenogami in the east. The percentage of spruce and balsam varies greatly but as a rule is not high. The trees show much early suppression but when suitable openings occur they make more rapid growth than on any other types. In moister situations, in this type, pure stands of these conifers sometimes occur.

The budworm injury in this type has been relatively slight. The protection offered by the hardwood and the scattered grouping of the conifers prevents heavy stripping. Plot No. 1 represents two acres in a depression occurring on a hardwood ridge which was cut over some seventy years ago. The age of the trees was about sixty-five years. Although these trees were quite severely fed upon, as shown by ring suppression, practically no injury resulted due to the abundant moisture supply and their vigorous, rapid growth. Plot No. 2 illustrates a nearby stand where conditions of growth were not quite so favourable. It represents the total of four separate one-tenth acre plots, and may be said to be quite typical of general conditions in this type. Plot No. 3, taken on higher ground on the Northwest Miramichi river, illustrates the worst injury seen in this type. It is mature forest which escaped the old Miramichi fire and is located on an unusually thin soil for these trees. There is also a rather high percentage of balsam.

PLOT No. 1.—Northern Hardwood Type, Bathurst, N.B.

D.B.H.	Balsam		Red Spruce		White Spruce		Maple	Beech	Yellow Birch	Poplar	Total
	Living	Dead	Living	Dead	Living	Dead					
6	54	3	13		12		37		5	7	
7	27	4	7		12		3		4	4	
8	25	2	12		15		4	1	1	8	
9	31	3	9		11		2		4	6	
10	22	5	10		10		2		3	4	
11	18		4		6					1	
12	38	5	7		36		3	1	7	7	
13	17	2	1		15			1	1		
14	9		1		16		2		1		
15	9	4	1		2				1	4	
16	2		1								
17					6		1				
18	2		1								
19					1		1				
20					1						
Total	255	28	67	0	143	0					493
Per cent species	57·3		13·5		29·2						
Per cent dead		5·7		0		0					5·7

Remarks.—Height, balsam, 80 feet; spruce, 90 feet; age, 65 years; first feeding, 1914. Entire stand in a small depression of two acres on a hardwood ridge cut over for larger hardwood and conifers seventy years ago, and partially burned. The soil is deep and well watered. Some of the white spruce were growing at the rate of one inch in diameter per year for several years. Only balsam was killed though ring retardation and renewed terminals were shown by all trees. The vigorous growth prevented serious injury.

PLOT No. 2.—Northern Hardwood Type, Bathurst, N.B.

D.H.B.	Balsam		Spruce		Beech	Yellow Birch	Maple	Hem-lock	Total
	Living	Dead	Living	Dead					
2	26	3	17	1	5	6	4	....	
3	12	3	12	....	1	7	1	....	
4	17	2	9	....	3	9	3	....	
5	19	5	12	....	3	1	4	....	
6	4	1	5	....	1	1	2	....	
7	2	....	2	2	2	....	....	1	
8	3	1	3	....	1	....	....	....	
9	4	1	3	....	1	....	....	....	
10	5	....	2	....	1	....	....	....	
11	....	....	2	....	1	1	....	....	
12	2	1	....	....	....	....	....	....	
13	....	....		....	1	1	....	1	
14	1	....	1	....	....	....	....	....	
15	....	....	....	....	1	....	....	1	
16	....	....	....	....	....	1	....	....	
Total	95	17	68	3	....	....	....	....	183
Per cent species	61·2		38·8		....	....	....	....	
Per cent dead		14·4		4·2	....	....	....	....	10·9

Remarks.—Height, 80 feet; age, 200 years; first feeding, 1914. Total of four one-tenth acre plots on typical hardwood ridge surrounded by spruce flat which latter was severely damaged (see plot No. 4). Pines and larger spruce periodically removed.

PLOT No. 3.—Northern Hardwood Type, Wayerton N.B.

D.B.H.	Balsam		Red Spruce		White Spruce		Beech	Maple	Yellow Birch	Totals
	Living	Dead	Living	Dead	Living	Dead				
2	5	13	1	1	1	1	4	2	....	
3	3	8	1	....	1	....	3	....	....	
4	2	9	....	....	2	....	4	1	1	
5	3	14	....	....	2	....	....	2	....	
6	1	16	2	....	1	....	2	1	....	
7	2	6	....	....	....	....	4	1	1	
8	....	5	....	....	....	....	8	2	1	
9	....	2	1	....	....	....	1	....	....	
10	....	3	....	....	....	....	5	....	....	
11	....	1	....	....	....	....	1	....	2	
12	....	....	1	....	....	....	....	....	3	
Totals	16	77	6	1	7	1	....	....	....	108
Per cent species	86·1		6·4		7·3		....	....	....	....
Per cent dead	....	82·8	....	14·3	....	12·5	....	....	....	73·1

Remarks.—Height, 65 feet; age, 200 years; first feeding, 1913; One-quarter acre plot in northern hardwood type, the pine and larger spruce having been removed some years ago. Located on poor soil for this type.

(Black) Spruce Swamp Type, Laurentian Region

This type as here defined is considered purely of the northern Laurentian region. It is one of the most uniform and characteristic types of these northern forests, occurring on poorly drained soils in small patches to very extensive areas. In all cases there seems to be an impervious stratum or subsoil. A thick ground cover of laurel or Labrador tea, sphagnum and lichens (caribou moss) is associated with this type. In this soil-cover the snow and ice remain for two or three weeks after it has melted elsewhere and plant activities are notably delayed in these sites in the spring. It is composed of dense stands of slow growing black spruce with rarely any other species except larch forming a mixture. Reproduction is generally very good.

The inability of the budworm larvæ to develop normally or mature in large numbers (see page 36) precludes excessive feeding in this type. The injury from a commercial standpoint is negligible. A few trees die but in no place has this been found to exceed one per cent of the stand. Quite a few terminals are killed and for several years ring suppression occurs, especially in the proximity to balsam areas. As much as three to five years increment may be lost. No plots were taken to illustrate this type.

(Black) Spruce Slope Type, Laurentian and Acadian Regions

This type resembles the black spruce bog type. It is also frequently mixed with jack pine and occasionally with larch and after fires often reverts to pure jack pine. Practically no balsam is found. The same soil-cover of heaths and mosses occurs though during dry seasons very little water is found beneath this cover. Usually, less sphagnum and more lichens are found than in the swamp type. On the northern limits of the Laurentian region it occurs frequently on the steep slopes and crests of the ridges.

As a rule this type has suffered very little injury though it does not stand up quite as well as the swamp type. On the headwaters of the Shipshaw river, Quebec, areas were observed where about one per cent of the trees had been killed. Possibly the drier conditions make recuperation from feeding more difficult.

South of the St. Lawrence river this same type occurs (so considered for the present).[1] It was seen to best advantage on the higher mountains in central New Brunswick and on the higher hills bordering the southern shore of the St. Lawrence. The budworm injury was negligible in all places where studied, but reports indicate high mortality in some areas.

Spruce Flat Type, Laurentian Region

This type occupies enormous areas of the northern portion of the Laurentian region. It extends in a continuous belt south of the height of land to the northern limit of the tolerant hardwood type and on the shallower soils, where there is less competition with other trees, south to the St. Lawrence valley. In western Quebec it extends some distance north of the height of land.

It occurs on all kinds of soils except where excessive moisture exists without drainage. On sandier soils jack pine frequently predominates. In mature forests, spruce and balsam form the greater percentage of the stand though frequently mixed with old white birches which become more abundant on the higher ground. Formerly an overstory of white pine often existed, usually from 200 to 400 years of age. This tree, however, has been largely cut. Practically no white pine regeneration occurs except after fires. White spruce occurs scatteringly usually along streams. Balsam reproduction is prolific but spruce is rather poor in most cases. However, spruce seems to be more tolerant in that it can recover from longer suppression and lives to a much older age, while balsam indifferently recovers from long suppression, is comparatively short lived and altogether a much less hardy tree. Consequently, there is a gradual increase in the percentage of spruce with the age of the stand and occasionally areas containing considerable spruce are encountered where no severe fires have occurred for 200 years or more.

The southern portion of this region has been extensively cut over for pulpwood and the result has been to increase greatly the hardwood forest.

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[1] Sufficient observations to determine this point were not made, though it is more likely this spruce is the same as throughout the Acadian region.

For this reason and also because of the greater proportion of tolerant hardwood type the amount of balsam was not sufficient to develop the epidemic to the extent that it did further north. The larger amount of second growth conifers was likewise important in lowering the mortality (see page 48). Consequently the injury was much less severe and more localized.

In the northern portion, lumbering has been confined to the removal of pine and larger spruce which has greatly increased the percentage of balsam.

Mature Forest

A large part of the more northern portions of this type occurs as mature forest usually with a higher proportion of balsam than spruce. Such forests offer ideal feeding conditions for the budworm and it is these forests which have suffered most severely in Quebec. The sample plots at Lake Opasatika illustrate this condition, while in eastern Quebec in an older outbreak more extensive studies were carried out in co-operation with Mr. O. Schierbeck, Forester for Price Brothers, Limited. It is quite safe to say that 75 to 90 per cent of the balsam in these forests has been destroyed. However, the black spruce has not suffered, except where it composed only a small fraction of the stand and died from the removal of the surrounding balsam.

The following sample plots of one acre each taken from Mr. Schierbeck's survey of the lake Kenogami watershed illustrate conditions in mature stands and are typical for much of northern Quebec. All trees are above 4 inches D.B.H.

—	Spruce	Living Balsam	White Birch	Dead Balsam	Per cent Balsam dead
Plot 19	4	0	40	251	100
Plot 36	62	0	43	364	100
Plot 8	16	17	16	334	95
Plot 12	0	145	20	165	53

Second Growth

Broadly speaking, second growth forests from 50 to 75 years of age suffered less severely even when small percentages of hardwood were present. Along the Shipshaw river this was well illustrated by the contrast between virgin forest where 75 to 100 per cent of the balsam is dead, while in adjacent second growth following a fire of some 80 years ago, an average of 15 per cent of the balsam was killed. The defoliation was the same but the younger trees are much more resistant to the effects of the injury. The following acre plots in second growth on the Lake Kenogami watershed illustrate this condition.

—	Spruce	Living Balsam	White Birch	Dead Balsam	Per cent Balsam Dead
Plot No. 17	15	255	101	122	32
Plot No. 18	5	367	12	210	36

Birch-Poplar Type, Laurentian Region

Mixed conifers and hardwoods of second growth form a transitional stage in the spruce flat type following fires. White birch, poplar, balsam, and spruce constitute the mixture. In some localities white birch predominates, in others, though less frequently, poplar predominates. The latter permits better growth of conifers and earlier maturity. After a single fire dense reproduction occurs, very heavily stocked with balsam and a lesser percentage of spruce (Plate X). Some areas of several square miles have been seen, almost uniformly restocked with these conifers, suggesting that the origin of such an even stand must have been from seed stored in the ground as in the case of Douglas fir. The hardwoods first overtop the conifers but the latter do fairly well up to forty or fifty years. From then on, the more vigorous softwoods break through the hardwood canopy while many die, chiefly balsam, from severe suppression. Seventy-five to one hundred years are required to produce any commercial sized conifers in this mixed type owing to the competition of the white birch and poplar, and the stand is often but indifferently stocked. The poplars die out much earlier and finally the birches gradually go from the top largely hastened by the bronze birch borer (*Agrilus anxius*). At this stage many suppressed spruce and fewer balsam recover, increasing the percentage of softwoods.

Up to the time the balsam starts breaking through the hardwood canopy no injury from budworm results. This character of stand is practically immune at about forty to fifty years of age, (on all but very thin soils), even after quite a few scattered coniferous crowns are through the stand. Some of the dominant terminals are killed but few trees die outright. After eighty to one hundred years a larger percentage of the softwoods get through; by this time the birch tops are becoming quite thin due to *Agrilus* killing the branches, and very severe injury may occur see plot 10, in fact it is not unusual for all the balsam to be killed. The reason for this is that there is enough contiguous balsam to furnish sufficient food for large numbers of caterpillars and consequent severe stripping and owing to the former suppressed condition of these trees they are unable to recover. The following data supplied by Mr. Schierbeck gives percentages of injury in a fifty-year stand which suffered very little.

	Spruce	Balsam	White Birch	Dead Balsam	Per cent Balsam Dead
Plot No. 13	30	275	47	7	2·5
Plot No. 14	17	357	55	5	1·4
Plot No. 10	0	540	60	30	5·3

(Red) Spruce Flat Type, Acadian Region

In many respects this type resembles the Laurentian spruce-balsam forest but in certain very fundamental respects it is quite different and is certainly so from the standpoint of budworm feeding and injury. It is a much faster growing tree, particularly in the development of the current year's growth, it reproduces very well under most conditions and has suffered severe injury from the budworm.

This type forms the bulk of the commercial spruce forests of New Brunswick and is developed in best form on the Miramichi plateau, the south shores of the St. Lawrence river and the Gaspe peninsula. The development of this type is much the same as that of the black spruce of the Laurentian. Its early history, following fires and clear cuttings, is similar, although owing to the usually sandy soil hardwood competition is less severe and due to the much better spruce reproduction pure stands following fires are quite common. On budworm areas where the stand was opened balsam reproduction is now prolific, as well as on diameter limit cuttings. On the other hand following fires or clear cutting spruce reproduction is usually predominant, occasionally almost pure. This type likewise with age gradually reverts to a higher percentage of spruce when it interfered with by man. This tendency is much more marked than in the northern black spruce. Red spruce is extremely tolerant and can withstand 100 years' suppression and when competition is overcome will make extremely rapid growth for another 50 to 100 years. On good soil trees were found reaching a height of 90 to 100 feet and 12 to 20 inches D.B.H. in sixty-five years.

This type was studied intensively at two localities at Fief St. Clare, Que., and on the Tabusintac river, N.B. Most of the discussion applies to those places though several other watersheds on the Mirimichi plateau were traversed and one watershed in western New Brunswick in the St. John drainage system. In a seigneurie of Price Brothers, Limited, at Fief St. Claire, Mr. T. Gloerson, the forester in charge, gave very valuable assistance and had already prepared a very accurate type map. This seigneurie contains about 12 square miles. The soil is very much the same over the entire area. It is a residual soil composed of a thin layer of sand and humus overlying a mass of broken red-brown or greyish-yellow sandstone streaked with quartz, known as the Sillery sandstone. Variations occur from thin or thicker layers of soil over the rocks to a good soil on irregular hills, probably glacial drift.

The other area on the Tabusintac river in New Brunswick was located on the limits of Snowball and Company; Mr. H. P. Webb, Forester of the Company, furnished maps of the region and directions as to certain features of interest in the studies. The greater part of the work was done along the Bathurst-Chatham road. This region is composed of sandstone and shales known as the Millstone Grit of the Middle Carboniferous. The soil is composed of rather deep sand of poor quality and subject to excessive drying. Occasionally, stiffer, deeper soils of clay and sand exist. These are occupied by tolerant hardwoods.

On the Northwest Miramichi river in the vicinity of Wayerton, N.B., and further west, several plots were taken on Precambrian schists and gneiss. The soil was exceedingly thin and rocky.

Mature Forest

All the mature forest studied had been more or less cutover in the past 100 years. Originally, the large white pines which evidently formed excellent stands were removed for sawlogs and later, periodically, the larger spruce. Old lumbermen say that about every fifteen to twenty years they expected to secure a cut of large spruce sawlogs. However, the cuttings were less frequent, at least, in the past fifty years and the trees removed were at each successive cutting of smaller diameter. Under conditions such as these, balsam often composed 50 per cent of the stand. It is this type of forest that has suffered so severely in the Acadian region. It has been explained how this mixture forms a most favourable food combination for the budworm (see page 36). Practically all the commercial balsam has been killed and from 40 to 60 per cent of the spruce. It was difficult to find pure red spruce in this forest due to previous lumbering and consequent increase in balsam. In a few places small stands were found which were never large enough to represent typical conditions or react to the budworm as a pure stand. Although the injury was slightly less than in higher balsam mixtures it suffered severely. Judging by effects on younger stands of red spruce, less injury would be expected in large areas of nearly pure spruce. Plots 4, 5 and 6 illustrate conditions in mature stands. It will be seen that in the smaller diameters a greater proportion of spruce than balsam remains to form a second stand.

PLOT No. 4.—(Red) Spruce Flat (Mature), Bathurst, N.B.

D.H.B.	Balsam		Spruce		White Pine	White Birch	Totals
	Living	Dead	Living	Dead			
3	3	32	10	5	....	....	
4	6	21	26	4	....	1	
5	4	31	13	10	....	....	
6	1	20	14	10	....	....	....
7	1	15	11	3	....	2	
8	....	6	12	2	....	....	
9	....	5	3	1	....	1	
10	....	....	6	4	....	....	
11	....	....	2	5	1	....	
12	....	....	1	4	1	1	
13	....	....	1	1	....	....	
14	....	....	2	1	....	....	
15	....	....	1	....	....	....	....
16	....	....	2	1	....	....	
Totals	15	130	104	51	....	....	300
Per cent species	48·3		51·7				
Per cent dead	....	90	....	33	....	....	60%

Remarks.—Height, 65 feet; age, 200 years; first feeding, 1914. Slightly over one-half acre, illustrating large areas of overmature spruce flats which have been repeatedly lumbered for pine and larger spruce; soil deep sand, very easily drying. Dense balsam reproduction and many small spruce of various ages up to ten feet in height occur.

PLOT No. 5.—Spruce Flat Type, N.W. Miramichi River, N.B.

D.B.H.	Balsam		Spruce		White Birch	Totals
	Living	Dead	Living	Dead		
2	10	8	12	14	....	
3	3	2	4	9	....	
4	....	8	5	10	....	
5	....	8	10	11	3	
6	....	11	5	12	....	
7	....	2	4	11	....	
8	....	2	3	7	....	
9	....	1	....	....	....	
10	....	1	....	5	....	
11	....	1	....	4	....	
12	....	....	1	1	....	
13	....	....	1	....	....	
14	....	....	....	1	....	
Total	13	44	45	85	....	187
Per cent species	30·4		69·6			
Per cent dead	....	77·2	....	64·4	....	69·9

Remarks.—Height, 60 feet; age, 200 years; first feeding, 1913. One-quarter acre taken in tenth acre plots, illustrating same conditions as plot No. 4, but occurring on Precambrian schists and gneiss, a very thin rocky soil. Some cutting occurred about six years ago.

PLOT No. 6.—(RED) SPRUCE FLAT TYPE, FIEF ST. CLAIRE, QUE.

A

D.B.H.	Balsam		Spruce		White Birch	Total
	Living	Dead	Living	Dead		
2	1	7				
3	1	1				
4	1	5	1		1	
5		4		1		
6	1	3	1		1	
7		4	2	1	2	
8	2	1			1	
9			5		2	
10	1	1	3		1	
11	2		1	2		
12		1	3			
13			2			
14			3		2	
15		1	1	1		
16			1			
17			5			
18			2			

B

D.B.H.	Balsam		Spruce		White Birch	Total
	Living	Dead	Living	Dead		
2	5	2	7			
3	1		5			
4	2	4	1	1		
5	2	4	1			
6		3	5	1		
7		6	1	3		
8		1	1			
9		1				
10		2	1			
11			1			
12						
13				1		
14				1		
15			1		2	
16			2			
17				1		

C

D.B.H.	Balsam		Spruce		Total
	Living	Dead	Living	Dead	
2		1	2		
3		3	2		
4		2	6	2	
5	1	5	7	2	
6	1	6	10	2	
7	1	2	2	1	
8	1	3	7		
9	2	2	3		
10			1		
11					
12			1		
13					
14			2		
15					
16					
17					

PLOT No. 6.-*Con.*—SUMMARY OF TWELVE ONE-TENTH ACRE PLOTS

Total Spruce and Balsam	Total per cent killed	Per cent Balsam	Per cent Spruce	Per cent Balsam killed	Per cent Spruce killed
37	84	92	8	85	67
52	88	90	10	97	0
47	62	89	11	57	0
43	54	84	16	53	43
51	87	83	17	75	22
29	38	69	31	50	11
24	33	62	38	33	33
52	67	52	48	92	40
72	46	51	49	76	14
57	56	49	51	70	24
80	39	38	62	80	14
87	12	38	62	21	6
Average	56	69	31	73	23

REMARKS.—Height, 70 to 75 feet; age, 200 years; first feeding, 1911. Summary of twelve plots in mature spruce balsam forest to illustrate character of injury. Three of these plots are given in detail (plot A, one-fifth acre; B, and C one-tenth acre, others one-tenth acre.) In most cases the greatest mortality in spruce occurs in the lower diameter classes.

Second Growth

Second growth red spruce and balsam suffered less injury than older forests. Plots 11A and B, illustrate conditions in a fairly large tract of pure spruce at Fief St. Clair, Que. Although some injury is shown, when compared to total injury in higher balsam mixtures these conditions are very good, especially if the density and recent competition are considered. Five per cent or more of balsam was sufficient to cause serious injury. Generally speaking 50 to 75 per cent of the balsam was destroyed in these mixtures while the greatest mortality in spruce was among the more suppressed trees. The tendency of the outbreak has been to reduce the percentage of balsam in these forests. A total of twelve one-tenth acre plots is summarized on a 100-year burn, plot No. 14. Plot No. 15 illustrates a total of twelve one-tenth acre plots on several square miles of a sixty-five-year burn. Comparison of these two age classes shows greater injury in the one-hundred-year-old forest. Plots 7, A and B, illustrate conditions in a hundred-year stand.

PLOT No. 7.—Second Growth Red Spruce and Balsam, Bathurst, N.B.

D.B.H.	A						B					
	Balsam		Spruce		White Birch	Total	Balsam		Spruce		White Birch	Total
	Living	Dead	Living	Dead			Living	Dead	Living	Dead		
2	......	2	2	6	......	......	......	1	2	......	......	
3	......	2	7	2	1	......	......	3	3	......	......	
4	......	2	8	10	1	......	......	4	4	2	......	
5	......	2	1	5	......	......	......	6	1	1	......	
6	......	1	5	11	1	......	......	4	2	3	......	
7	......	3	7	9	1	......	......	3	1	2	......	
8	......	2	6	3	1	......	......	3	6	5	......	
9	......	......	4	4	......	......	......	4	2	1	......	
10	......	2	4	2	......	......	......	1	1	1	1	
11	......	2	1	......	......	......	......	1	1	......	......	......
12	......	......	......	......	......	......	......	......	......	......	......	......
13	......	1	2	......	......	......	......	......	......	......	......	......
14	......	1	......	......	......	......	......	......	......	......	......	......
Total	0	20	47	52	......	119	0	30	23	15	......	68
Per cent species	16·5		83·5		......	......	44·1		55·9		......	
Per cent dead	......	100	......	52·5	......	60·5	......	100	....	39·5	......	66·2

Remarks.—Height, 65 feet; age, 100 years; first feeding, 1914. Two one-tenth acre plots on an old clearing on flat sandy soil. These are very densely stocked stands on which the rate of growth has greatly slowed down the past ten to twenty years, showing total destruction of balsam and nearly 50 per cent of the spruce destroyed. Spruce that recovered is making better growth and the stand is converted into pure spruce.

In several localities thirty and forty year stands of spruce-balsam mixtures were studied. These reacted very well to the budworm feeding, rarely suffering enough injury to seriously affect the stand. The trees that were killed are chiefly among the smaller diameter classes comprising the suppressed trees. Destroyed terminals are quickly restored and to all appearance these stands show no evidence of budworm injury a few years later except on close inspection. Plots 18 and 19 illustrate conditions in forty or thirty year balsam-red spruce reproduction.

Birch-Poplar Type, Acadian Region

The same suppression and thinning of the conifers takes place in red spruce —balsam hardwood mixtures, as noted for the black spruce mixtures, though more spruce finally predominates, plots 9, A to E, illustrate this condition when compared with plot 15 A taken about 100 yards away and similar comparisons are shown by plots No. 10, A and B and 11 A in a hundred-year stand. The protection afforded by hardwoods is only effective while the hardwood canopy is dominant. After this, especially when the hardwoods are becoming decadent, severe injury takes place, as illustrated by plot No. 10, A and B in a hundred-year stand. An attempt was made to arrive at the lowest percentage of hardwoods necessary to afford protection, but it was found impractical because of the influence of other factors, such as age, thriftiness of the conifers and density. Poplar seems to afford as much protection as birch and at the same time allows more rapid height and diameter growth and greater percentages of conifers. A quarter acre, plot 12, taken less than one-half mile from plot No. 9 illustrates this condition. Plot No. 13 illustrates a younger poplar mixture on the north shore of the Saguenay, Que.

PLOT No. 9.—Second Growth Softwoods and Hardwoods, Bathurst, N.B.

D.H.B.	A					C				
	Balsam		Spruce		White Birch	Balsam		Spruce		Birch
	Living	Dead	Living	Dead		Living	Dead	Living	Dead	
2	1	....	18	....	6	7	....	1	....	....
3	2	......	14	....	5	10	....	4	....	4
4	....	....	22	....	3	11	....	3	....	3
5	....	....	17	....	1	8	....	1	....	7
6	....	....	10	....	2	6	1	....	....	8
7	....	....	2	....	1	....	1	1	....	6
8	....	....	....	....	....	1	....	1	....	....
9	....	....	....	....	....	1	....	....	....	3
10	....	....	....	....	....	....	1	....	....	2
Total	3	....	83	....	18	44	3	11	....	33

D.B.H.	B					D					
	Balsam		Spruce		Birch	Balsam		Spruce		White Birch	White Pine
	Living	Dead	Living	Dead		Living	Dead	Living	Dead		
2	3	......	16	1	2	8	......	21	4	9	3
3	3	......	6	1	2	2	......	15	......	5	2
4	2	......	15	1	7	1	......	17	1	4	......
5	5	......	6	......	5	2	......	22	......	2	......
6	......	......	7	......	14	......	......	18	......	5	1
7	2	......	1	......	15	......	......	8	......	......	......
8	2	......	1	......	2	......	......	3	......	......	......
9	1	......	......	......	......	......	......	1	......	......	1
10	......	......	......	......	2	......	......	......	......	......	......
11	......	......	......	......	1	......	......	......	......	......	......
Total	18	......	52	3	50	13	......	105	5	25	7

PLOT No. 9—*Continued.*

E

D.B.H.	Balsam		Spruce		White Birch	White Pine
	Living	Dead	Living	Dead		
2	5	....	10	....	4	....
3	3	....	8	....	4	....
4	3	....	12	1	6	....
5	3	....	12	1	3	2
6	4	....	3	1	5	....
7	5	....	6	....	5	1
8	....	....	2	....	4	....
9	....	....	....	....	1	....
10	....	....	....	....	1	....
Total	23	....	53	3	33	3

REMARKS.—Height, 55 to 65 feet; age, 65 years; first feeding, 1914. Five one-tenth acre plots to illustrate slower growth of conifers in mixed hardwoods and protection from budworm while overtopped. Compare these plots with nearby pure softwood, numbers 15 A, B, C, D, on same burn and with plots number 10A, B on a 100-year burn at Fief St. Clair, Que. A few of the spruce here incuded are white.

PLOT No. 10.—SECOND GROWTH SPRUCE AND HARDWOODS, FIEF, ST. CLAIRE QUE.

D.B.H.	A								B					
	Balsam		Spruce		White Birch	Pop-lar	Cedar	Tota'	Balsam		Spruce		White Birch	Total
	Liv-ing	Dead	Liv-ing	Dead					Liv-ing	Dead	Liv-ing	Dead		
2	1	8	1	7	......	......	......	....	4	5	......	......	1	
3	1	7	8	5	1	......	1	.....	2	20	1	......	4	
4	.....	2	6	5	3	......	......	.....	3	9	......	......	3	
5	.....	6	3	1	1	......	......	.....	3	9	......	......	6	
6	.....	2	2	1	1	2	......	.....	6	2	......	......	6	
7	.....	2	2	0	2	......	......	.....	1	3	......	......	6	
8	.....	2	5	3	3	......	......	.....	1	3	1	......	9	
9	......	4	3	......	......	......	......	......	......	......	......	......	4	
10	......	......	1	......	1	......	......	.....	......	......	......	......	......	
11	......	......	......	......	......	......	......	.....	......	......	......	......	......	......
12	......	......	......	......	......	......	......	....	......	......	......	......	1	
13	......	......	......	......	......	......	.....	.....	......	......	......	......	......	......
Total	2	33	31	22	....	....	....	88	20	51	2	0	....	73
Per cent species	39·8		60·2						97·2		2·8			
Per cent dead	.....	94·3	......	41·5	......	......	......	62·5	.....	71·8	......	0	.....	70

REMARKS.—Height, 60 feet; age, 100 years; first feeding, 1911. Two one-tenth acre plots to illustrate suppression of conifers in mixed stands and severe budworm injury to conifers after long suppression. The hardwoods are beginning to deteriorate. Compare with plot 11A, taken near by on same soil.

PLOT No. 11.—Second Growth Red Spruce, Fief St. Claire, Que.

D.B.H.	A							B						
	Balsam		Spruce		White Birch	White Pine	Total	Balsam		Spruce		White Birch	White Pine	Total
	Liv.	Dead	Liv.	Dead				Liv.	Dead	Liv.	Dead			
2			3	2	1	1		3	2	33	11	1		
3			2	1				3	4	35	7	1		
4			3		1				2	43	9			
5	1	1	1	1	1				2	40	21			
6			7	2		1			1	79	19			
7		1	5	1		1			2	37	13			
8			8							24	7		1	
9			6		1					10				
10	1	1	3			1				3				
11		1	2											
12					1									
13					1									
14				1										
Total	2	4	40	8			54	6	13	304	87			410
Per cent Species	11·1		88·9					4·6		95·4				
Per cent Dead		66·6		16·6			22·2		68·4		22·2			24·4

Remarks.—Height, 65 feet; age, 100 years; first feeding, 1911. Plot A one-tenth acre taken nearby 10A; Plot B total of three one-tenth acre plots on more rocky slope within one-quarter mile of A. To illustrate better growth of conifers as compared to Plot 10 and to show relatively less injury in comparison with the mixed hardwoods. There still remains sufficient trees to produce a well stocked stand. Also compare with plot 14 of higher balsam mixtures.

PLOT No. 12.—Second Growth Conifers and Poplar, Pisiquit Brook, N.B.

D.B.H.	Balsam		Red Spruce		White Spruce		Poplar	White Birch	Total
	Living	Dead	Living	Dead	Living	Dead			
2	3	5				1			
3	11	4		1		1	2	1	
4	10	8	4	1	4	8	7		
5	13	1	8	1	6	8	13		
6	17	3	5	1	7	6	10		
7	11	1	4	2	5	1	12		
8	3	1			5	1	10	1	
9	2				4		5		
10	3			1			4		
11							2		
Total	73	23	21	7	31	26			181
Per cent Species	53·0		15·4		21·6				
Per cent Dead		26		25		45·6			30·9

Remarks.—Height, 85 feet; age, 65 years; first feeding, 1914. One-quarter acre plot in a poplar mixture showing greater height of trees and more uniform larger size. Very few of the larger trees were killed and probably many of the smaller ones were shaded out rather than budworm killed. The growth for the past ten years had greatly slowed down on all killed trees. This area of some two acres contrasted sharply with nearby birch mixtures.

PLOT No. 13.—Second Growth Conifers and Poplar, Saguenay River, Que.

D.B.H.	Balsam	White Spruce	Poplar	White Birch	Cedar
2	12	26	3	10	2
3	3	15	2	3	...
4	1	3	11	2	...
5	2	5	9	2	...
6	2	5	2	...	...
7	...	3	4	...	...
8	...	3	5	1	...
9	...	...	2	...	...
10	...	...	2	...	...
11	...	...	...	...	...

Remarks.—Height, spruce, 40 feet; poplar, 50 feet; age 40 years; first feeding, 1911. One-fifth acre plot on a burn illustrating mixture of poplar and softwoods and immunity from budworm. A few killed terminals and ring suppression resulted but no mortality. The poplar is already dying out below three inches and conifers below five inches show some suppression.

PLOT No. 14.—Second Growth Red Spruce and Balsam, Fief St. Claire Que.

D.B.H.	A					B				
	Balsam		Spruce		White Birch	Balsam		Spruce		White Birch
	Living	Dead	Living	Dead		Living	Dead	Living	Dead	
2	...	11	3	3	1	...	3	...	3	...
3	...	15	2	6	2	...	2	2	3	1
4	1	17	2	1	5	...	1	4	11	...
5	...	8	3	...	1	...	4	...	3	1
6	...	17	4	1	6	...	4	4	5	1
7	...	14	5	4	5	...	9	3	7	2
8	...	5	3	1	5	...	10	8	6	2
9	...	...	3	...	3	...	1	1	1	...
10	...	1	4	...	3	...	...	...	2	...
11	...	...	...	...	...	...	...	...	...	...
12	...	...	...	...	...	...	...	...	...	2

C

D.B.H.	Balsam		Spruce		White Birch
	Living	Dead	Living	Dead	
2	1	3	1	2	...
3	...	1	...	2	...
4	2	2	4	1	...
5	...	4	3	5	...
6	1	8	1	14	1
7	...	5	9	11	1
8	...	...	7	6	1
9	...	...	2	1	1
10	...	...	1	...	...
11	...	...	...	1	...
12	...	...	...	1	...

SUMMARY OF TWELVE PLOT

Total Spruce Balsam	Total Per cent Killed	Per cent Balsam	Per cent Spruce	Per cent Balsam Killed	Per cent Spruce Killed	
134	80	66	34	99	31	Plot A
192	86	54	46	100	60	⅛ A
109	77	53	47	94	52	....
76	50	50	50	80	42	....
52	58	40	60	95	32	....
172	55	37	63	100	29	⅕A
97	77	35	65	100	65	Plot B
99	68	27	73	85	61	Plot C
54	22	11	89	66	17	....
85	32	8	92	86	27	....
254	23	4	96	64	20	¼A
73	20	1	99	0	21	
Average	54	32	68	77	38	

REMARKS.—Height, 60 to 65 feet; age, 100 years; first feeding, 1911. A total of twelve plots selected in various places in a five square mile burn of 100 years to show variation in injury and character of stand. Three of the plots are given in detail. All plots are one-tenth acre except where indicated.

PLOT NO. 15.—SECOND GROWTH RED SPRUCE AND BALSAM, BATHURST, N.B.

D.B.H.	A					B					
	Balsam		Spruce		White Birch	Balsam		White Spruce		Red Spruce	
	Living	Dead	Living	Dead		Living	Dead	Living	Dead	Living	Dead
2	15	6	2	....	2	....	....	....	....	....	....
3	6	5	2	3	2	....	....	1	1	3	....
4	4	5	2	....	....	....	....	1	....	1	....
5	....	6	....	1	1	....	1	3	2	1	1
6	1	5	1	1	1	....	1	3	2	3	....
7	....	1	1	1	....	1	1	2	....	3	....
8	1	1	....	....	2	....	2	3	2	1	....
9	....	2	2	....	....	1	1	5	1	5	1
10	....	2	....	....	....	....	1	2	1	2	1
11	....	....	....	....	....	....	2	2	....	1	1
12	....	....	1	....	....	....	2	2	....	2	....
13	....	....	1	....	....	....	....	1	....	....	1
14	....	....	2	....	....	....	1	....	....	....	....

D.B.H.	C						D			
	Balsam		Spruce		White Birch	White Pine	Balsam		Spruce	
	Living	Dead	Living	Dead			Living	Dead	Living	Dead
2	....	18	1	......	1	....	6	13	18	9
3	....	20	3	1	1	....	2	14	11	6
4	3	20	5	....	....	....	1	15	7	5
5	2	19	3	1	1	....	1	10	6	5
6	....	17	2	....	....	....	2	9	2	1
7	....	15	4	....	....	1	3	7	8	1
8	2	14	1	....	....	....	....	3	1	....
9	....	4	....	....	....	....	....	3	1	....
10	....	....	....	....	....	....	....	....	1	....
11	....	....	....	....	....	....	....	....	....	....
12	....	....	....	....	....	1	....	....	1	....

SUMMARY OF TWELVE PLOTS

Total Spruce and Balsam	Total Per cent Dead	Per cent Balsam	Per cent Spruce	Per cent Balsam Killed	Per cent Spruce Killed	—
85	61	85	15	66	31	
155	77	80	20	95	10	Plot C
80	50	75	25	55	30	Plot A
115	53	70	30	60	35	
85	62	61	39	70	48	
172	59	52	48	83	32	Plot D
101	18	48	52	24	6	
195	30	47	53	35	29	
66	21	27	73	6	40	
57	0	23	77	0	0	
76	34	18	82	85	23	Plot B
127	5	9	91	16	14	
Average	40	50	50	50	25	

REMARKS.—Height, 55 to 60 feet; age, 65 years; first feeding, 1914. A total of twelve one-tenth acre plots on a 65 year burn to show variable conditions of injury. The plots are summarized and several are illustrated in full. These were all taken in an even aged stand under practically identical conditions.

(RED) SPRUCE SWAMP TYPE, ACADIAN REGION

The red spruce swamp type or slow growing red spruce on poorly drained situations is considered as a distinct type from that north of the St. Lawrence river. It has much the same plant association and forms stands just as compact over quite large areas. Rarely has any balsam been found in this type as described for more southern localities.

In some places this type has suffered severely, even to almost total destruction. This condition is unusual and confined to smaller areas of very poorly formed stands. Generally speaking, the injury rarely exceeds 10 to 20 per cent and is confined to the smaller suppressed trees. As a rule the stands only suffer a severe thinning, sufficient trees being left to produce a commercial stand. Plot No. 16, A and B, illustrate samples in a extensive area of this type.

PLOT No. 16.—(RED) SPRUCE SWAMP TYPE, WAYERTON N.B.

D.B.H.	A							B		
	Balsam		Spruce		White Birch	White Pine	Total	Spruce		Total
	Living	Dead	Living	Dead				Living	Dead	
2	5		9		1			50	22	
3	1		4		3			64	12	
4			10	2	1			78	22	
5			9	3	2			79	21	
6			22	1	2	1		98	29	
7	2		31	5		1		44	4	
8	1		31	3		2		14		
9			18	1						
10			15	1						
Total	9	0	149	16			174	427	110	537
Per cent Species	5		95							
Per cent Dead		0		9·7			9·2			20·5

REMARKS.—Height, A 65, B 55 feet; age, 100 years; first feeding, 1913. Two one-half acre strips taken in pure red spruce 100 years of age following the Miramichi fire. The trees show a decided reduction in rate of growth for the past 15 to 20 years and have no doubt reached a point where the stands were too dense for the soil on which they were growing. Sufficient material is left to produce a good stand and the effects of the budworm are hardly apparent until actual counts are made. Increased growth is resulting from the thinning.

PLOT No. 17.—Second Growth Red Spruce and Balsam, Bathurst, N.B.

D.B.H.	A						B				
	Balsam		Red Spruce	White Spruce	White Birch	Total	Balsam		Spruce		Total
	Living	Dead					Living	Dead	Living	Dead	
2	16	......	......	2	2	......	4	10	5	1	
3	21	......	4	4	3	......	2	13	7	1	
4	23	......	9	......	4	......	4	17	2	1	
5	14	......	5	......	1	......	2	8	4	1	
6	12	......	1	......	......	......	1	8	5	1	
7	1	......	1	......	......	......	2	3	4	......	
8	3	......	1	......	......	......	1	2	1	......	
9	......	......	1	......	......	......	......	......	1	......	
10	......	......	......	......	......	......	......	......	1	......	
Total	90	0	22	6	......	118	16	61	30	5	112
Per cent Species	76·2		23·8		......	......	68·7		31·3		
Per cent Dead	......	0	......	0	......	0	......	79·2	......	14·3	59

Remarks.—Height, A 60 feet, B 50 feet; age, 60 years; first feeding, 1914. Comparison of two one-tenth acre plots within 50 yards. Plot A on slope of stream bank, plot B on flat above. The great contrast in injury here was very marked along this slope. It is attributed to deeper soil and more moisture available on Plot A; also the fact that A was located in a narrow belt more exposed, while B was in a continuous dense stand on the flat some 25 feet higher.

PLOT No. 18.—Second Growth Red Spruce and Balsam, Fief St. Claire

D.B.H.	A						B					
	Balsam		Spruce		White Birch	Total	Balsam		Balsam		White Birch	Total
	Living	Dead	Living	Dead			Living	Dead	Living	Dead		
2	18	20	19	4	5	......	12	15	12	6	2	
3	11	8	18	......	5	......	5	8	10	2	1	
4	6	1	13	......	3	......	1	1	8	......	1	
5	7	......	3	......	......	......	1	1	6	......	2	
6	4	......	1	......	......	......	......	......	1	......	1	
7	2	......	......	......	......	......	......	......	......	......	......	......
8	1	......	......	......	......	......	......	......	......	......	......	......
Total	49	29	54	4	......	136	19	25	38	8	......	90
Per cent Species	57·3		42·7		......	......	43·8		51·2		....	......
Per cent Dead	......	37·2	......	6·9	......	24·3	......	56·8	......	17·4	......	36·6

C

D.B.H.	Balsam		White Birch	Total
	Living	Dead		
2	6	26	2	
3	12	7	6	
4	3	4	....	
5	0	1	....	
6	2	....	1	
7	1	....	....	
Total	24	38	....	62
Per cent Dead	....	....	....	61·3

Remarks.—Height, 30-40 feet; age ,40 years; first feeding, 1911. Three one-tenth acre plots, to illustrate effect of feeding, in 40-year reproduction. Plots A and B were on an old abandoned farm of deep soil, while plot C was on a thin soil on an old burn. Those trees killed were chiefly the smaller suppressed ones many of which would have died later. There still remains sufficient to make a well stocked stand in Plots A and B. The proportion of balsam has been reduced. Destroyed terminals have all been replaced.

PLOT 19.—SECOND GROWTH SPRUCE AND BALSAM, BATHURST, N.B.

D.B.H.	Balsam	Red Spruce	White Spruce	White Pine	White Birch
2	47	7	21	2	0
3	34	18	29	1	0
4	12	9	23	5	1
5	1	1	5	1	2
6			1	1	1
7					
8					

REMARKS.—Height, 25 feet; age, 30 years; first feeding, 1914. One-tenth acre plot in reproduction on abandoned farm. No trees died from budworm attack and all injured terminals have been replaced. Occasionally young stands are seriously injured but as a general rule the injury is not heavy.

WHITE SPRUCE

White spruce has a wide distribution in other types. However, it is frequently found pure in small blocks chiefly on old farm land and after fires. It is much more exacting in its requirements, preferring deep, usually clayey soils and abundant moisture, such as on river flats. Under such circumstances it is the fastest growing conifer in these forests. In New Brunswick it is more generally distributed than in Quebec and occasionally has been found on situations where it makes poorer growth than red spruce. Previously the general immunity of this tree has been explained but on the poor thin soils just mentioned the percentage of dead trees equalled that of red spruce. Where white spruce has been killed the trees were of low vitality in that they had practically ceased growth for some ten to twenty years previous to the budworm attack. This lowered vigour combined with favourable seasons for budworm development (see feeding habits page 36) is assumed to be the reason for high mortality. Just how extensive areas of pure white spruce will react to the budworm cannot be stated from observation. However, on better soils, the natural requirements of this tree, it is possible that it may withstand budworm attacks better than any other native species.

CAUSES OF BUDWORM OUTBREAKS

There can be no doubt that budworm epidemics can develop only when there is sufficient balsam[1] in the forests over wide areas. The history of past outbreaks (see Introduction) seems to occur in the same region at intervals of some fifty years which would roughly correspond to the time required for a new generation of balsam to become dominant. Furthermore, the early outbreaks were very much more restricted, becoming more severe and widespread, culminating in the present one which has covered such enormous areas in Quebec, New Brunswick and Maine.

Early descriptions of the forests of Maine and New Brunswick indicate that they were composed largely of spruce and pine. Within more recent times the forests of Quebec were described as much the same. In other words, the percentage of balsam was relatively much less than just before the present outbreak. Early logging operations in these forests began in more accessible regions along the coasts and larger waterways. They were intensely selective, since first the white pine was removed, and at later intervals the larger spruce, balsam being entirely disregarded. This selective cutting (Zon, 1904) rapidly increased the percentage of balsam due to the latter being left in the forest and to the better reproductive qualities of balsam under such conditions.

[1] Mixtures of white and red spruce furnish equally favourable food, but this combination has not been found common over extensive areas.

The older epidemics followed the course of these logging operations, becoming more extensive as exploitation proceeded further into the virgin forests. At present few parts of the budworm injured area have not been culled for the pine and larger spruce, producing a proportion of balsam sufficient to support the epidemic over the entire area, once it developed momentum in any section.

The history of the present outbreak indicates that it developed independently at several points over a period of some ten years. Certain areas were not seriously injured during this outbreak, notably the Gaspe peninsula, the north shore of the St. Lawrence and the more southern portion of the Laurentian region. In the two former regions comparatively little logging has been done, while the latter has been very consistently logged for pulp, the balsam removed and large areas replaced by hardwoods. It is likely that in the future local outbreaks will occur in these regions as soon as balsam gains a certain dominance in the forests. It is predicted that in the region of the headwaters of Metis and Patepedia rivers and east where the present outbreak died out from unknown causes and where a high percentage of dominant balsam exists we can expect another outbreak at any time.

INFLUENCE OF BUDWORM EPIDEMICS ON FOREST TYPES

Very little attention has been given to the consideration of the effect insects have in the development of existing forest types. The widespread epidemics of *Dendroctonus* species in the pine forests, the attack of white pine weevil in young growth pine and hardwoods, the hickory bark-beetle in hickory, *Agrilus* in birch, the gipsy moth and spruce budworm all produce marked effects in the establishment and development of various forest types. Graves, 1908, briefly mentions thinning made by insects, Ashe, 1922, definitely mentions *Dendroctonus frontalis* and *Scolytus quadrispinosus* as affecting forest types and Pierson, 1922, notes the effect of *Pissodes* in white pine.

It appears from data collected during the present budworm outbreak that this insect plays an important role in the establishment of the permanent spruce forests of northeastern United States and Canada.

Briefly, the history of the development of a spruce-balsam forest subsequent to a fire is as follows. The young growth appears as a coniferous hardwood mixture. In youth the hardwoods over-top the conifers the latter finally gaining dominance. After maturity of the white birch, in 80 to 100 years, it is thinned out through competition of the softwoods which process is rapidly accelerated by *Agrilus* attack in the crown. In this transition type balsam is usually more abundant than spruce, particularly north of the St. Lawrence river. The dying of the birches likewise produces better conditions for balsam regeneration while the percentage of spruce has increased very little so that we usually find after the first 100 to 125 years considerably more balsam. Such conditions are ideal for a budworm epidemic which appears and destroys a much higher percentage of balsam than spruce (compare sample plots.) The older the stand the more severe and selective the balsam thinning. Spruce has much better recuperative powers both from natural suppression and from budworm defoliation, consequently a larger number of spruce fill the gaps left by the balsam. The intensity of this conversion to pure spruce varies directly with the original percentage of balsam as well as with the age of the stand. Where the percentage of balsam was about 50 or more the opening made by the deadening is ideal for prolific regeneration of a ground cover of balsam, on the other hand where less balsam existed before the attack the density of the stand is not lowered so much and less balsam reproduction occurs. Under the former conditions a certain amount of the balsam reproduction will eventually gain dominance though to a less degree than originally occurred.

In the spring of 1922, an opportunity was found to study stumps cut the previous winter of a spruce-balsam forest over 200 years of age, on the south shore of the St. Lawrence river. Three budworm epidemics could be traced. One of 1806 of considerable severity; another of 1877 of less severity and the present of 1911 of great intensity. That of 1877 was well marked only in the balsam. Few balsams were found over 100 years of age and none showing a period of good growth for more than 50 years. The spruce all showed a marked period of good growth for some 50 years following 1820 and a less decided acceleration following 1880, and extending to suppression caused by the 1911 outbreak. Thus, these spruces clearly showed the influence of the balsam thinning and practically no balsam living to-day went through the 1806 outbreak.

It is therefore logical to assume that the budworm plays an important role in the rotation of these trees and in the conversions of mixed spruce-balsam forests into a pure spruce stand. Once this latter stage is reached it is more nearly budworm proof, until interference by man or natural forces, such as wind, fire or the attack of *Dendroctonus piceaperda* on the large mature trees, disturb the conditions and bring about a repetition of the process.

It is true that mixed spruce-balsam stands would in time develop into purer spruce stands due to the shorter life of balsam and its lesser ability to recover from suppression yet there can be little doubt that the budworm accelerates this process and is a fundamental factor in its accomplishment.

POSSIBILITIES OF PREVENTION AND CONTROL

We may expect budworm outbreaks in the future. The time of their occurrence and severity will depend largely on the condition of the forests, in respect to the percentage of balsam. It is impossible to predict what the future condition of these forests will be since such is entirely dependent on the method of cutting and occurrence of fires. The present methods of cutting by diameter limit gradually tend to increase the percentage of balsam. On the other hand, the present outbreak has practically destroyed all merchantable balsam except in a few areas and in second growth stands and it has left a dense mass of balsam reproduction on the ground.

It is likely we will never have another outbreak as extensive as the present, but what we may expect is smaller outbreaks covering lesser areas and occurring at more frequent intervals. Certain areas which escaped serious injury because the forests were second growth mixed with hardwoods will present favourable conditions for the budworm in from ten to twenty years. Other areas which escaped in this outbreak are now in excellent condition for an outbreak at any time.

When we stop to consider the enormous territory invaded by the present outbreak, the rapidity with which the damage is accomplished and the inaccessability of our forest regions we realize that any artificial means of control are hopeless except possibly on some very valuable, easily accessible and restricted areas. We, therefore, cannot hope to control an outbreak once it has started, and our only hope is to prevent a recurrence of it. The prevention of a recurrence of the budworm is purely a question of forest management. Conditions must be developed that are least favourable to the enormous multiplication of this insect and least susceptible to injury so that future outbreaks can be rendered much less potent, and the losses reduced to a minimum. Following the high mortality during a budworm outbreak the weakened trees continue to die for some five to ten years. In these areas there will be a possibility of salvaging some of the dead timber and in preventing some of the remaining trees from dying from beetle attack.

MANAGEMENT OF VARIOUS FOREST TYPES

Zon (1908) in discussing forest types, says: "The closer the composition of the forest is in accord with the physical conditions of the situation, the more resistant it is to dangers of all kinds, insects, snow, etc., the easier is its treatment, the greater results can be obtained from the application of one or another method of thinning, and the more certain is its reproduction. European foresters were at one time carried away with the idea of a pure forest, and later with the idea of a mixed forest, as a panacea for all dangers to the forest and a guarantee of the success of all cultural operations. We now know that only a forest growth which is perfectly suited to the physical conditions of the situation proves resistant to all natural dangers that may threaten it, no matter whether it is pure or mixed. A forest type possessing the most valuable quality—stability—is, therefore, the ideal to which a forester must strive in regenerating and caring for his forest."

The importance of this conception of forest types cannot be too strongly emphasized in order to secure budworm proof forests. In fact it, no doubt, equally applies to all serious insect enemies of the forest. Very exact environmental conditions are necessary for their unusual multiplication and consequent injury. Fortunately, such environmental conditions are usually maladjustments of stable conditions brought about by decadence of the stand or interference of outside agencies, frequently man. Fortunately again, these favourable insect environments are in direct opposition to all ethics of good forest management, and it may not be too optimistic to predict that our serious native forest insect pests will be of minor importance when sound forest practices are adopted.

It is only intended here to bring together some of the suggestions from various sources concerning the management of these forest types affected by the budworm. In fact, from a review of the literature treating of the management of spruce, it is evident that considerable more experimental work is needed before satisfactory methods will be evolved. All the suggestions given here refer to the use of these forests for growing pulpwood.

Northern Hardwood Type

This is relatively speaking a budworm-proof forest. Suggestions have been advocated for converting it into a spruce forest. The generally deep soil would no doubt produce quick rotations of conifers that due to their rapidity of growth and earliness of maturity would be less severely injured than the same trees on poorer sites. However, the advisability of this procedure is questionable on several grounds. This type serves to break up the continuity of the coniferous canopy in the region where it exists; it acts as a very effective firebreak; it will supply a class of hardwoods which will doubtless have a future demand and it will offer a certain supply of a limited amount of softwood in case of future budworm outbreaks. Since spruce reproduction is generally poor after softwood cuttings, Mr. Schierbeck (Report to Directors Price Brothers, Limited) suggests planting white spruce with the hardwoods in this type and managing for the production of both intolerant hardwoods and spruce. Frothingham, 1915, presents a good discussion of these forests and methods of management.

(Black) Spruce Swamp Type, Laurentian Region

This is likewise a budworm proof type. Without draining these areas it will be impossible to grow any other trees than spruce and larch in this situation. Wickenden, 1921, gives the following recommendations for handling this type. "Since it is extremely slow growing many trees are mature before reaching the Quebec Government diameter limit of seven inches, and furthermore it usually contains a fairly even distribution of all age classes, I propose that this type be treated by simply cutting trees over average size of trees over fifty years of age in each stand, also that all trees that are sickly or damaged be removed."

(Black) Spruce Slope Type, Laurentian and Acadian Region

Like the swamp type these forests are practically immune from serious budworm injury. However, due to the fact that jack pine does very well on this same site, that it is not attacked by the budworm and that it is a faster growing tree, it is suggested that these areas be converted into jack pine. Wickenden's (1921) suggestions in this respect are as follows: " For the time being I would propose a cut to remove mature and decaying trees, leaving a fair number of healthy trees per acre, mostly jack pine, which will be found growing among this black spruce, and which will be the following crop, and through which in its turn the black spruce will again propagate."

" It has been noticed that after a fire this class of forest produces more rapidly and it may be found advisable at a later date to go even as far as applying light and controlled burning to these areas."

(Red) Spruce Swamp Type, Acadian Region

Generally speaking this type is budworm proof or the injury is not sufficient to cause very serious consequences. It should be encouraged as it is probably the best tree for the site. Suggestion for management given under the discussion of the black spruce swamp type of the Laurentian region may be applicable here.

Spruce Flat Type

The spruce-balsam forests of both the Laurentian and the Acadian regions have suffered more extensively than any other type.

Spruce Flat Type, Acadian Region

Much discussion and experimental work has been devoted to the management of this type but there still seems to be a decided lack of agreement as to the best method of handling, particularly in reference to securing reproduction. Formerly, selection systems were advocated or merely cutting to certain diameter limits. Recent observers on the results of this procedure more or less agree that it is unsatisfactory in that it produces a higher percentage of fir, and hardwoods (see Murphy, 1917; Linn., 1918; Hawley, 1920). The diameter limit cutting in the New Brunswick forests has produced essentially the same results and has made possible the present budworm injury. More recently clean cutting to a merchantable diameter limit has been recommended and utilization or girdling of the hardwoods.

There seem to be three possibilities of producing budworm proof forests in the red spruce region: 1. The adoption of silvicultural practices promoting rapid growth. 2. The production of mixed softwood-hardwood stands. 3. The utilization of thin, easily drying soils for pine forests.

1. The relation between mortality from defoliation and rate of growth or vigour of the stands has been previously mentioned in several instances. It is planned to devote further study to this phase of the problem and until the results of such investigations are ascertained little more can be said. It seems, however, that with the approaching necessity of growing future crops of timber, better forest practices, promoting rapid growth, will be possible and that a high degree of immunity can thus be obtained.

2. Mixed hardwood-softwood second growth is budworm proof until the trees are about fifty years of age. It is nature's method of reproducing this type

and has the advantage of being very easily obtained. The disadvantages of such a type are the longer time required to produce merchantable conifers, the present difficulties of utilizing hardwoods and more poorly stocked stands of conifers.

By judicious thinning in early life these mixtures should produce much more thrifty softwoods, heavier stocked stands and shorter rotations. Under present conditions any additional expense, such as thinning, is out of the question except where there is a market for poplar or birch.

Poplar is extensively used for pulp in the United States and white birch is growing in favour. The most serious objection to these trees is the difficulty of transportation by water routes. It is very essential that further experiments be conducted to determine the most expedient methods of preparing these woods for river driving or other methods of transportation; also the best method and time of girdling to prevent sprout formation and drying of the wood. The entire problem of forest management in these pulpwood regions hinges on the utilization of these hardwoods.

3. A very characteristic feature of this epidemic is the much greater mortality on thin soils which are subject to excessive drying, and on poorer sites. It is proposed that such land be employed for jack pine for pulpwood or other pines for sawlogs. Nearly everywhere jack pine already exists in variable proportions and after fires restocks such soils. It grows well here and it should not be difficult to secure a stand. A combination of white spruce, jack pine and red spruce suggests excellent possibilities, as illustrated by many square miles of such mixtures following the Miramichi fire. Clean cutting followed by slash burning has been recommended in cases where some jack pine is already on the ground. Sterrett (1920) contributes a good discussion of the silvicultural features and management of jack pine.

Areas of jack pine will help in producing diversified forest conditions and breaking up the continuous spruce-balsam canopy.

Spruce Flat Type, Laurentian Region

The management of the spruce-balsam type of the Laurentian region presents much greater difficulties than that of the Acadian. The very poor reproduction of the black spruce and the more active competition of hardwoods in mixed stands present serious difficulties. Very little experimental work has been done and only a few papers have been published on the management of this type. (Consult MacCarthy 1919, 1921, A & B, McCarthy and Robertson, 1921, Wickenden, 1921.) Until we know more concerning the silvicultural features of black spruce and the various races of this tree any suggestions are hazardous. Elimination of balsam is out of the question under such circumstances. Its prolific seeding, its capacity for natural reproduction, its tolerance and rapidity of growth, producing pulpwood in fifty to sixty years must certainly be considered. Little in favour of it can be said from the budworm standpoint. It can be grown with hardwoods to be immune, and younger stands up to forty to fifty years (if thinned possibly to fifty or sixty years), go through the outbreaks with a fair percentage of recovery on the deeper soils. The greatest objection to encouraging large areas of pure balsam is that it produces ideal conditions for the development of extensive outbreaks.

It is, therefore, very important that these areas be managed to secure a large proportion of mixed hardwood-softwood reproduction. The stands should be developed in blocks of different age-classes so as to have as large a portion as possible in younger, less affected stands and to reduce the total amount of unprotected balsam after removal of the hardwoods.

Black spruce has suffered very slight mortality under any conditions. It can be grown with balsam in any proportion.

Everywhere in this type of forest abundant balsam reproduction covers the ground following the present outbreak.

Under these conditions the following recommendations are suggested for managing this type:—

Clean cutting to the smallest possible diameter limit on balsam.

The retention of black and white spruce seed trees to produce a higher percentage of these trees, especially white spruce.

Utilization of balsam on a short rotation.

Utilization of hardwoods to make possible proper management of mixed softwood-hardwood second growth.

On thin soils subject to excessive drying and poorer sites budworm immune trees such as jack pine or white pine should be grown.

Slash Disposal

Slash disposal has been advocated as an urgent necessity in these forests to make possible adequate fire protection, reduce losses from wood rotting fungi and secure better conditions for regeneration. Several large operators have suggested their willingness to adopt such measures if it is made compulsory so that the costs may fall upon all concerns alike.

From the insect standpoint slash disposal must be considered from the specific insects in question, the species of tree and the character of the slash. In the case of balsam no species breeding in balsam slash attack living trees. In spruce *Dendroctonus piceaperda* feeds both in felled trees and living trees. Several species of *Ips* likewise will breed in slash and living spruce but in no case have such outbreaks been known to continue more than one year in the living trees. Graham (1922) describes experiments conducted in Minn., the results of which are in harmony with the present standpoint. Hopkins (1922) briefly summaries his observations as follows: "Since the problem of slash disposal considered by the foresters and some entomologists that slash is an insect hazard to the living timber, I want to say that the results of more than thirty years of observations and some detailed study of the problem indicate that as a rule it is not, but, as in all rules, there are of course exceptions to this one. There are a few cases as related to certain types of forests, time of year, and cases of sporadic cutting, where the slash is dangerous, not so much from the insects that breed in the tops, logs, and stumps as that it serves to attract the tree-killing insects to the locality and from thus being concentrated they attack and kill the living timber. Continued logging operations, after they are once started within a given area, provide continuous breeding places for the insects and their natural enemies and thus the slash serves as a protection to the living timber.

"As related to the dangerous bark-boring insects that follow the defoliation of the fir and spruce, they rarely breed in slash and certainly not in the tops and branches.

"The disposal of slash, therefore, as a protection against insects is rarely necessary. Protection against fire is another story, but the cost of disposal for this purpose is to be charged to fire, and not to insect hazard."

Until more definite experiments are conducted it is not logical to asssume that slash disposal is necessary in the northeastern forests purely to prevent serious outbreaks of primary insects. These opinions are not intended to apply generally to all forest regions but only to the insects and trees under discussion.

There are many species of borers and timber beetles which breed in slash and also attack sawlogs causing enormous losses through defects which reduce the grade of the products. Clean forest conditions would greatly reduce the numbers of these species and consequently lessen the losses to crude forest products. Again the pine-sawyers (*Monochamus* spp.) do much injury through their feeding habits (see page 21). This destruction of the branches considerably lowers the seed production and not infrequently may be largely responsible for the death of the trees. Thus from the standpoint of spruce seed trees left after logging operations slash disposal might be advisable.

Close utilization, low stumps and small tops will go far in avoiding any serious consequences from slash breeding insects.

Control of Secondary Insects

In the discussion of the death of the trees in the foregoing pages it has been shown that secondary insects are only of importance after the budworm has disappeared. Many of the remaining weakened balsams are apparently killed by the balsam sawyer, *Monochamus marmorator*. In younger forests the trees dying after defoliation often form a larger percentage of the total mortality than those which died during the outbreak. These trees can be recognized by the red foliage. It was considered possible to reduce this subsequent mortality to a minimum by removal of the beetle infested trees during the winter and placing them in water or utilizing them within a month after the ice breaks the following spring.

In the winter of 1921-22 Price Brothers Limited, conducted a control operation, under such conditions, on an area of three square miles in the Shipshaw river district in Quebec. The amount of beetle infested timber removed was about 171,000 feet.

An examination of this area in the winter of 1922-23 showed that practically no trees had died during 1922. Not a single red-top of 1922 was found on the control area. However, even on the check area and remainder of the watershed extremely few infested trees were observed. On the control area the number of *Monochamus marmorator* and *Pissodes dubius* were greatly reduced. Only a few trees were found showing the attack of these beetles in 1922, while on the check area they were nearly as abundant as the previous year.

It is difficult to draw any definite conclusion from this experiment at present. Results were undoubtedly affected by the unusually wet and favourable growing season of 1922 as compared to 1921 suggesting that these beetles are of little importance in bringing about the death of the tree or require other adverse conditions to successfully attack. Mr. M. B. Dunn reports that in central New Brunswick similar absence of red-tops was noted in 1922 where in 1921 they were very abundant. It will be interesting to follow results through the next few years to see if the marked reduction of beetles in the control area has any effect on the number of dying trees. In both areas there are still many trees that have been making very little growth since the budworm outbreak in 1910, though many of these seemed to recover somewhat during the season of 1922.

Salvage of Budwormed Timber

The deadening has been so extensive that comparatively little of the budwormed timber in these forests will be salvaged from the present outbreak. Certain companies have made laudable efforts to salvage as much as possible and in New Brunswick a wise policy of granting lower stumpage rates in proportion to the injury has done much to make this possible. Unless the trees are cut the winter following their death they are greatly reduced in value for saw-logs due to defects from borers. Balsam can be utilized for pulp for some three years and spruce for possibly 4 to 5 years after death but even then due to rots the increased costs hardly justify the operations if allowed to stand so long. This rot-affected balsam can only be floated on short drives.

One concern in Quebec has made a systematic effort to salvage a certain area containing some 1,500,000 cords of dead wood, but at the best not over 600,000 could be saved. On balsam, wood-rotting fungi so reduced the sound wood of standing trees that 20 per cent of the logs were classed as culls.

In the future it is probable that due to the greater scarcity of wood and better accessibility of the areas much more of this character of timber can be salvaged and the total losses much reduced. The following suggestions are offered for bettering conditions following budworm outbreaks:

All limits should be explored within three to five years after the first feeding and logging operation concentrated on these areas where the greatest amount of dead timber or red-foliaged trees are found. The percentage of red-topped balsam or sparsely foliaged spruce, indicates the rate of dying.

Yearly examinations should be made through the limits as long as dying trees are in evidence.

In conducting logging operations the areas should be cut to the smallest merchantable diameter limit.

It is often useful to determine the length of time the trees have been dead. This can be done, especially for spruce, for trees dead from one to four years, by an examination of the insects in the trunk. The following rules are given which are applicable to practically the whole of Quebec and New Brunswick except the lower border of the former province where *Monochamus* life cycle is completed in one year. They are, as given, applicable only in the late spring or early summer just before or after the buds open.

Recently dead (since insect activities of previous summer). Inner bark sound; ambrosia beetles or bark-beetles just attacking; later in summer *Monochamus* egg scars and young larvæ.

Dead one year. Inner bark decaying and moist; old ambrosia beetle tunnels; maturing bark-beetles or larvæ; *Monochamus* larvæ half grown, entering wood.

Dead two years. Inner bark dry; sap rots evident; no living bark-beetles present; *Monochamus* prepupal larvæ in cells or later in summer fresh exit holes.

Dead three years. Inner bark dry; sap rots more evident; *Monochamus* old exit holes (with edges brown as compared to fresh holes of trees dead two years.)

With a little experience this can be made applicable at all seasons of the year by proper allowance for insect development.

Artificial Methods of Control

When the next budworm outbreak occurs the value of certain accessible and limited forest areas may be sufficient to undertake direct methods of control. The methods of direct control which may be applicable are, by spraying or dusting to kill the budworm larvæ, or removal of balsam from the stand to produce unfavourable conditions for feeding.

Either of these methods hinges on the rapidity of development and spread of an outbreak and the accessibility of the forest area in question. We know very little of the early development of a budworm outbreak but from the enormous areas attacked the first year during the present epidemic it must have developed with astonishing rapidity. However, it is probable that few trees die as the result of the first year's feeding. This allows one year between the first appearance of the insect and application of direct control measures.

Accessibility of the forest area is a prime factor in direct control operations. With such large areas of unorganized and inaccessible lands as exist at present practically nothing can be done. These forested areas must be considered as permanent investments yielding a yearly return and permanent improvements in the shape of roads and lines of transportation must be maintained. The employment of a permanent system of forest rangers and fire guards who should be capable of recognizing insect outbreaks in their incipient stages would be necessary to head off an outbreak of the budworm.

Spraying or Dusting.—Spraying or dusting by usual methods and from aeroplanes to kill the larvæ has been referred to by several writers, Johannsen (1913); Swaine (1922 A, B). There may be possibilities in this respect but probably not with any type of machine now in use due to the danger of flying low over forested areas. Several considerations are necessary before such measures can be recommended. No experiments have been conducted to determine how effective spraying or dusting will be against budworm larvæ. Due to the concealed habits of feeding it may be difficult to poison them. Applications just before the opening of the buds to poison the larvæ as they enter, or after most of the new growth is consumed, would probably be most effective. The effects of wholesale application of poison in the forest might be very injurious to bird and animal life. On limited areas spraying would have to be carried out from three to five years to kill the insects coming in from surrounding infested regions.

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PLATE I

FIG. 1.—*Balsam No. 2, St. Claire:* Transverse section of the wood from the apical portion of the stem of a tree which recovered from the effects of budworm defoliation. First feeding in 1911. Note late frost injury near inner margin of 1910 ring and reduction in width of succeeding growth layers, particularly during the 1913–1918 period. X 9.

FIG. 2.—*Balsam No. 2, St. Claire:* Transverse section of the wood from the median portion of the stem, showing loss of an annual ring during the 1913–1918 period. X 9.

FIG. 3.—*Balsam No. 2, St. Claire:* Transverse section of the wood from the basal portion of the stem, showing loss of three growth layers during the 1913–1918 period, and the formation of a "false ring" and traumatic resin cysts during the later part of the 1919 growing season. The latter abnormalities are due presumably to *Pissodes dubius* Rand. X 9.

FIG. 4.—*Balsam A, St. Claire:* Transverse section of the wood from the upper portion of the stem of a tree which recovered from the effects of budworm defoliation, beginning in 1911. Note late frost injury near the inner margin of the 1910 ring and zone of resinous tissue in outer portion of the much narrower 1911 growth layer. X 9.

Plate No. I

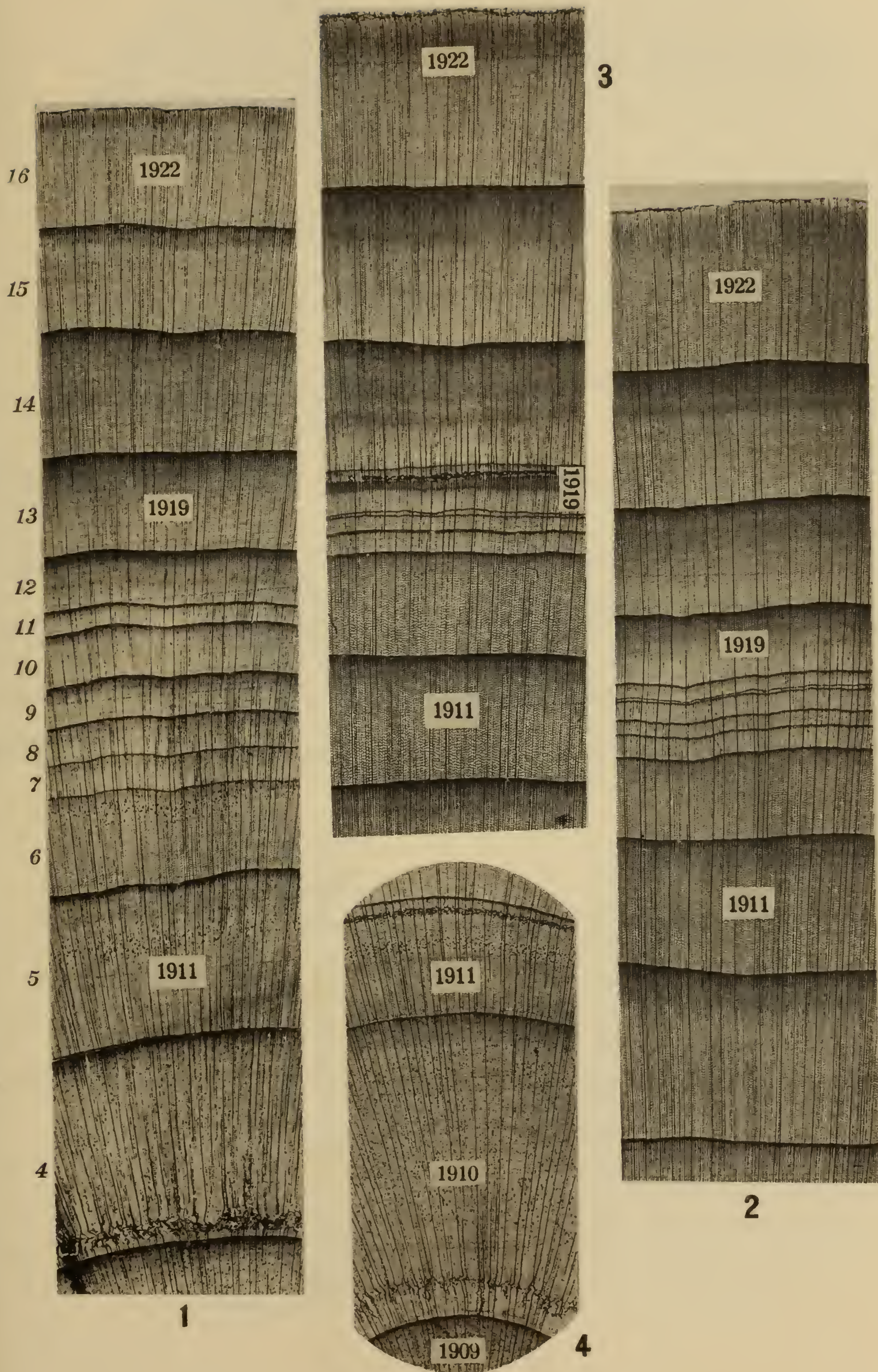
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PLATE II

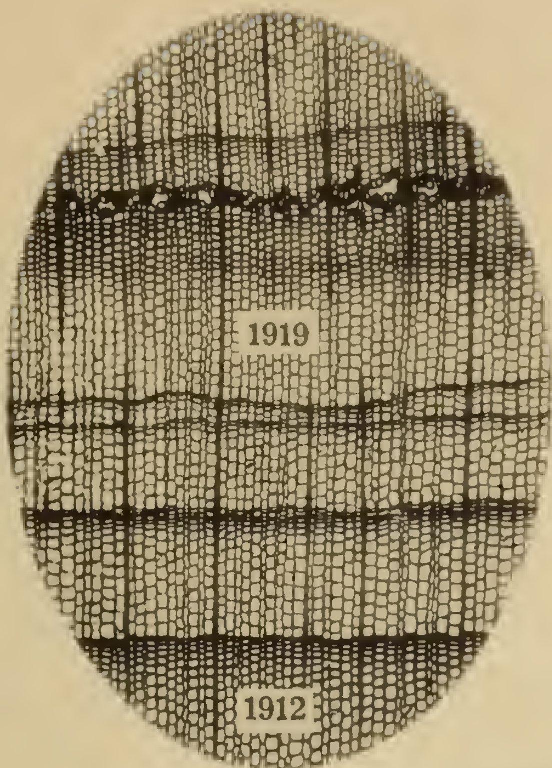
Fig. 5.—*Balsam No. 2, St. Claire:* Portion of fig. 3 more highly magnified, showing three growth layers formed during the 1913–1918 period and traumatic resin cysts in the outer portion of 1919 ring. X 30.

Fig. 6.—*Balsam No. 2, St. Claire:* Transverse section of the wood taken from the same disk as fig. 5, but from a different radius, showing four growth layers formed during the 1913–1918 period. X 30.

Fig. 7.—*Balsam No. VI–15:* Transverse section of peripheral portion of the wood from a stem attacked by *Pissodes dubius* Rand., showing traumatic resin cysts formed by the feebly active cambium X 30.

Fig. 8.—*Balsam No. 2, St. Claire:* Portion of fig. 2 more highly magnified, showing five annual rings formed during the 1913–1918 period. X 30.

Fig. 9.—*Balsam A, St. Claire:* Transverse section of 1909 growth layer of apical portion of the stem, showing normal distribution of resin cells. The 1909 ring is the second ring out from the pith and was formed two years before the first feeding of the budworm. X 30.



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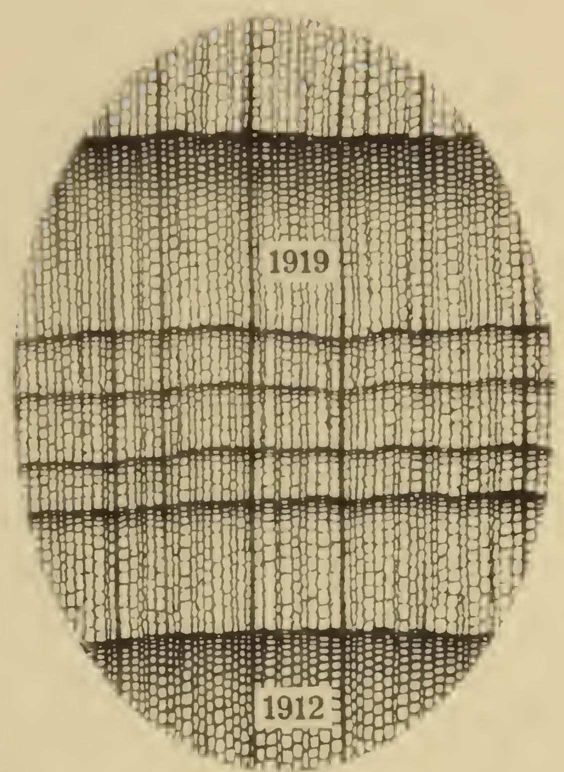

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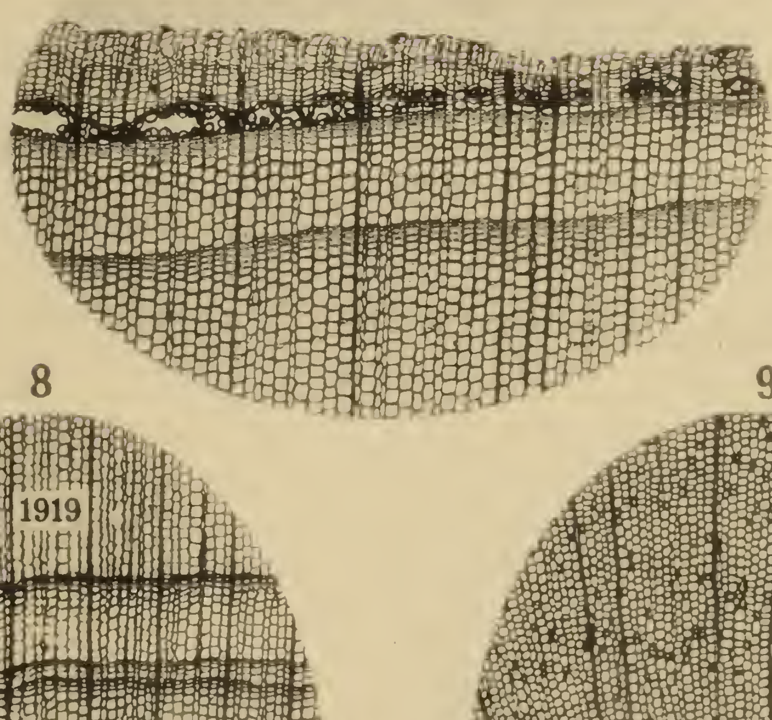

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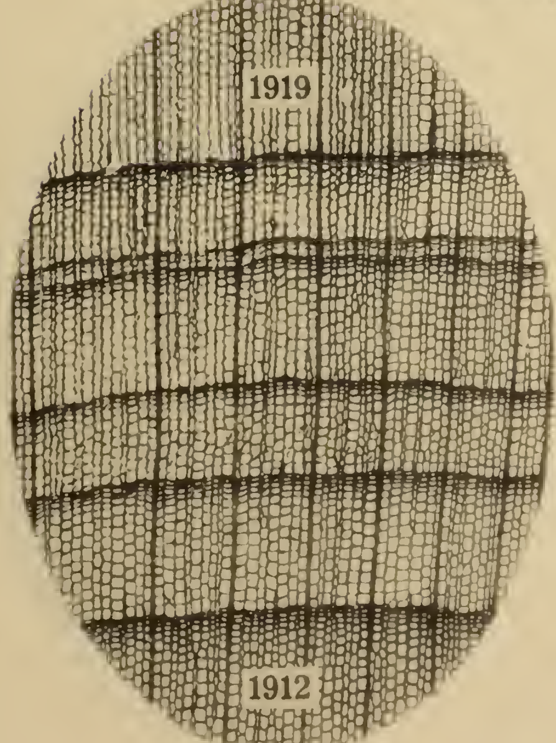

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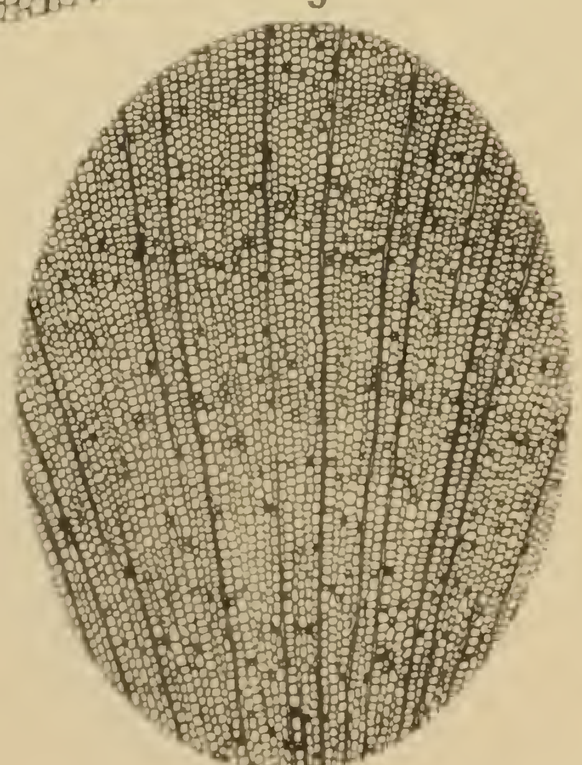


PLATE III

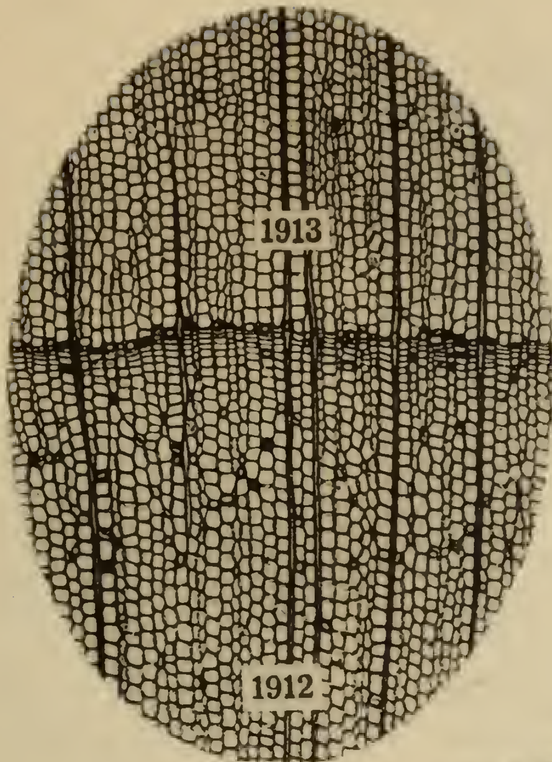
FIG. 10.—*Balsam No. 2, St. Claire:* Portion of fig. 1 more highly magnified, showing narrow zone of "summerwood" and marginal aggregation of resin cells in 1912 ring. X 42.

FIG. 11.—*Balsam No. VI–28, Saguenay:* Transverse section of 1911–1913 growth layers of apical portion of the stem, showing zonal distribution of resin cells and resin cysts. First feeding in 1911. X 27.

FIG. 12.—*Balsam No. 2, St. Claire:* Portion of fig. 1 more highly magnified, showing late frost injury near inner margin of 1910 ring. X 27.

FIG. 13.—*Balsam No. VI–28, Saguenay:* Transverse section of wood formed 15 feet lower in the stem than that shown in fig. 11. X 36.

FIG. 14.—*Balsam A, St. Claire:* Portion of fig. 4 more highly magnified showing zonal distribution of resin cells and resin cysts. X 36.



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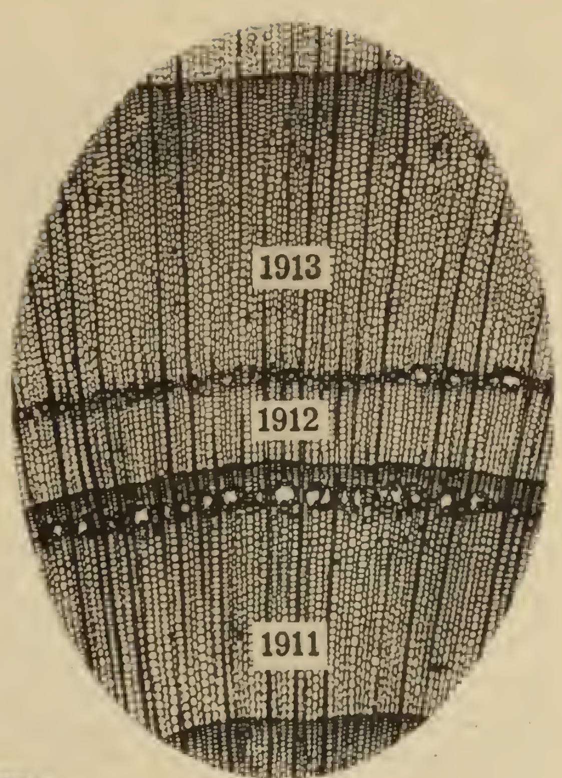

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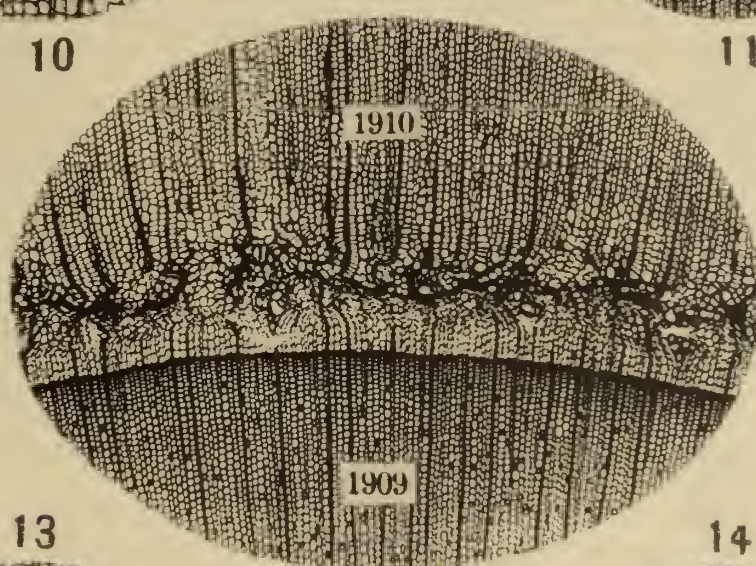

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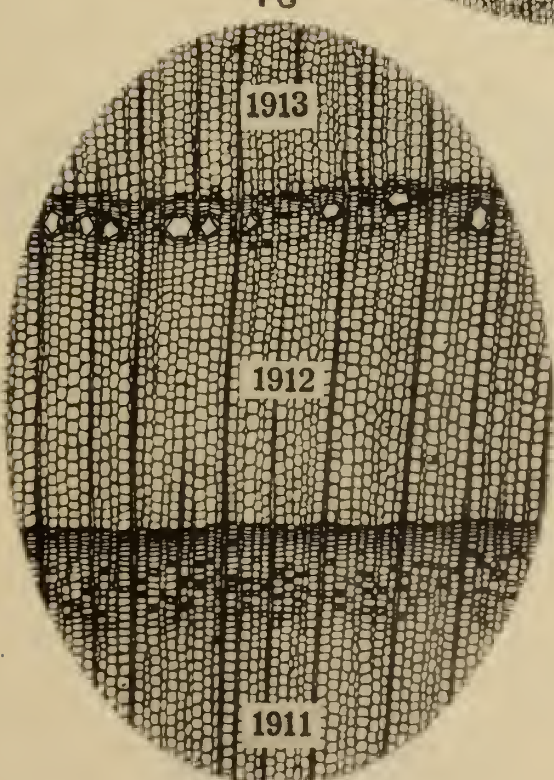

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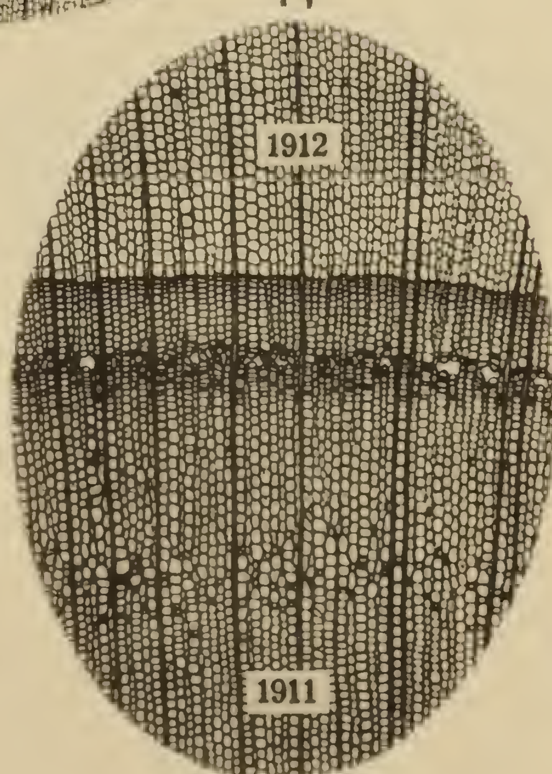


PLATE IV

Fig. 15.—*Balsam 86, Long Lake:* Transverse section of the wood from the upper portion of the stem of a tree which died during the late summer of 1922, four years after the first feeding of the budworm; showing reduced cambial activity during the 1918–1922 period. The 1921 layer is very narrow and tends to fade away on certain portions of the circumference of the stem. X 10.

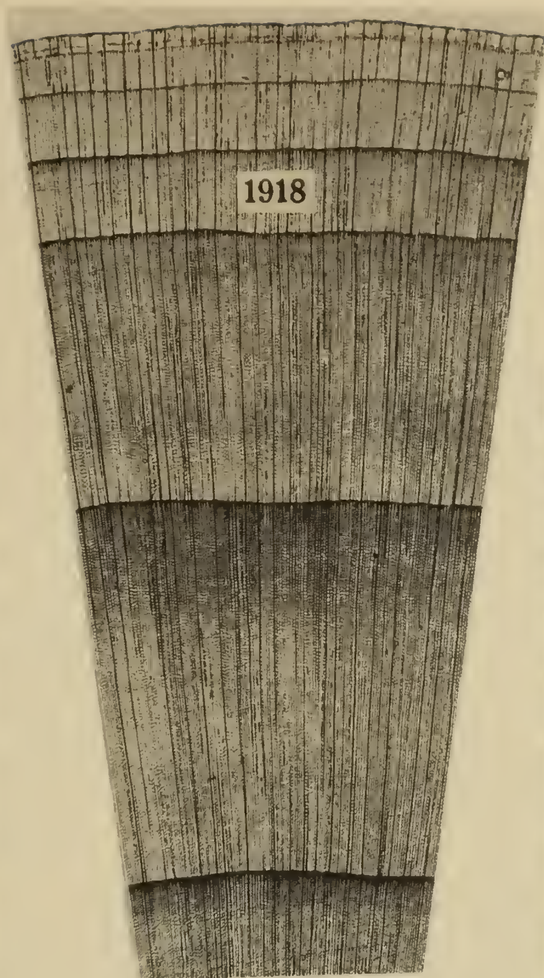
Fig. 16.—*Balsam 86, Long Lake:* Transverse section of the wood from the median portion of the stem showing absence of one growth layer. The 1918 ring is slightly wider than that formed during 1917. X 10.

Fig. 17.—*Balsam 86, Long Lake:* Transverse section of the wood from the basal portion of the stem, showing absence of 1921 and 1922 rings. The 1918 growth layer is considerably wider than that formed during 1917. X 10.

Fig. 18.—*Balsam No. 7, Long Lake:* Transverse section of the wood from the upper part of the stem of a tree which died during the late summer of 1922, four years after the first feeding of the budworm; showing reduced cambial activity during the 1918–1922 period. Note late frost injury near inner margin of 1918 ring and zone of resin cells at junction of 1920 and 1921 rings. X 16.

Fig. 19.—*Balsam No. 7, Long Lake:* Transverse section cut at a somewhat higher level in the stem, showing more conspicuous development of resinous tissue. X 18.

Plate No. IV



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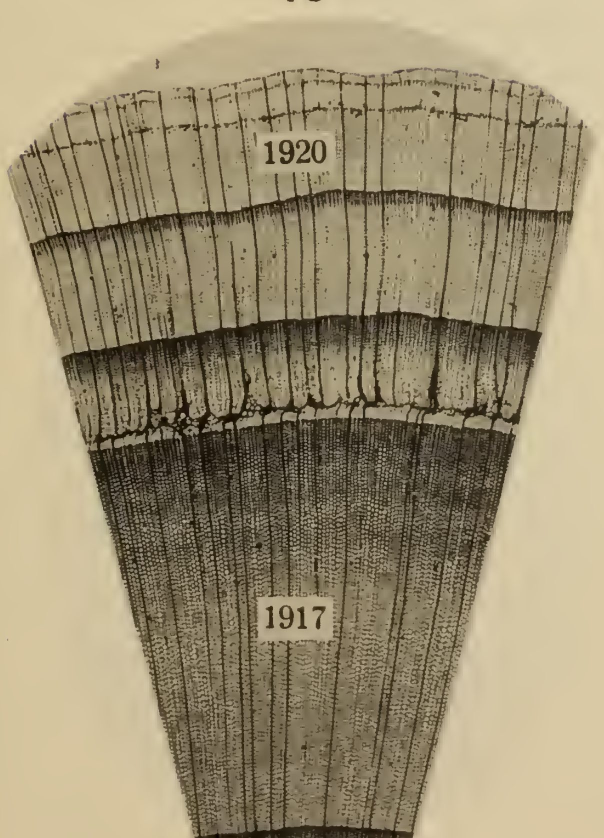

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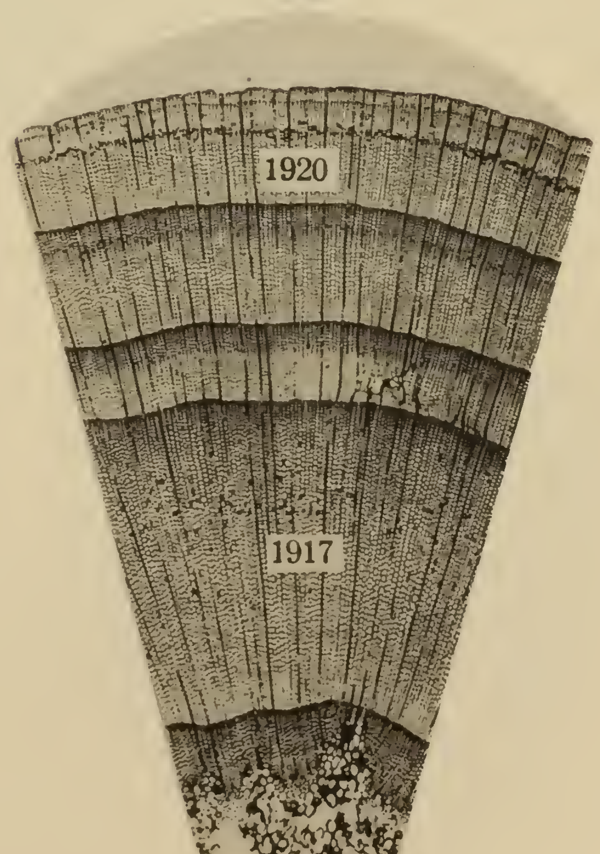


PLATE V

FIG. 20.—*Balsam No. 7, Long Lake:* Portion of 1918–1922 rings of fig. 19 more highly magnified, showing zonal distribution of resin cells in 1918 and 1919 growth layers and traumatic resin cysts near the outer margin of the 1920 ring. X 45.

FIG. 21.—*Balsam No. 4, Long Lake:* Transverse section of the five outermost rings of disk from the apical portion of a tree which died during the late summer of 1922, four years after the first feeding of the budworm; showing zone of resin cysts at the junction of the 1920 and 1921 rings. X 60.

FIG. 22.—*Balsam No. 7, Long Lake:* Portion of section shown in fig. 18 more highly magnified. Note distribution of resin cells and very feeble development of the 1922 growth layer. X 160.

FIG. 23.—*Balsam No. 7, Long Lake:* Portion of fig. 20 more highly magnified, showing resin cysts near outer margin of 1920 ring and feeble development of the 1922 growth layer. X 80.

FIG. 24.—*Balsam No. 86, Long Lake:* Transverse section of the wood from a higher level in the stem than that shown in fig. 15. Note resin cysts on the outer margins of 1919 and 1920 rings and clear differentiation of the 1921 and 1922 growth layers. X 80.

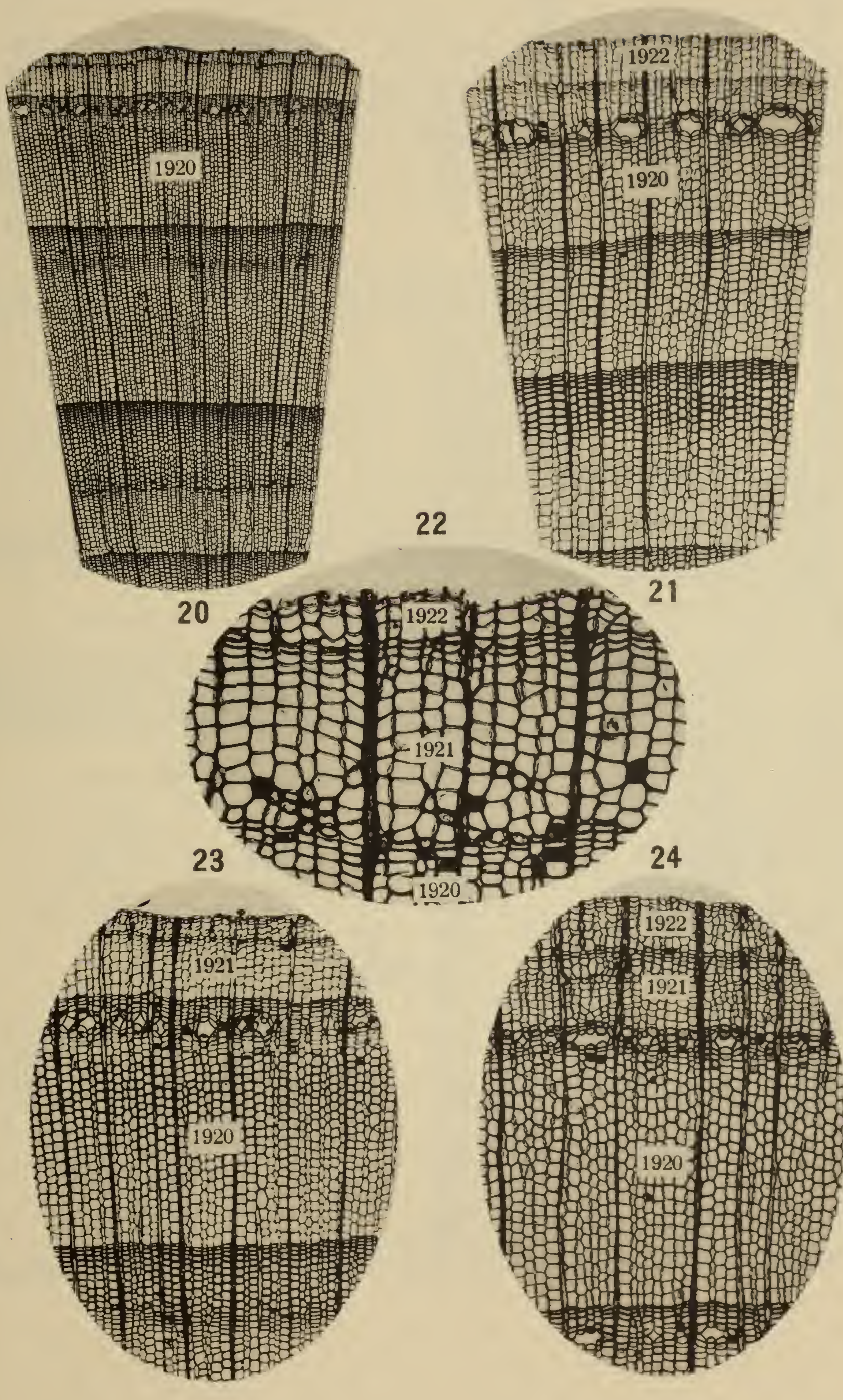

20
1920
21
1922
1920
22
1922
1921
1920
23
1921
1920
24
1922
1921
1920

PLATE VI

Fig. 1.—Average growth of balsam, white and black spruce buds at Lake Opasatika, Quebec, on June 1, 1922. Black spruce buds just opening (2nd figure from left) balsam (figure on right) and white spruce (remaining two) ten days after opening. Note abundance of food furnished by new growth of white spruce as compared to balsam and black spruce.

Fig. 2.—Twig of white spruce, needles partly removed for two previous years by budworm.

Fig. 3.—Roots of two balsam trees growing within a few yards of each other, pulled from wet soil. Above, tree under hardwood and not defoliated. Below, tree defoliated four years yet still containing many green needles.

Fig. 4.—Balsam twig showing three years light feeding when developing buds were not destroyed, only the needles along axis being eaten.

Fig. 5.—Characteristic renewal of terminal of red spruce. Five years after feeding stopped.


1
2
3
4
5

PLATE VII

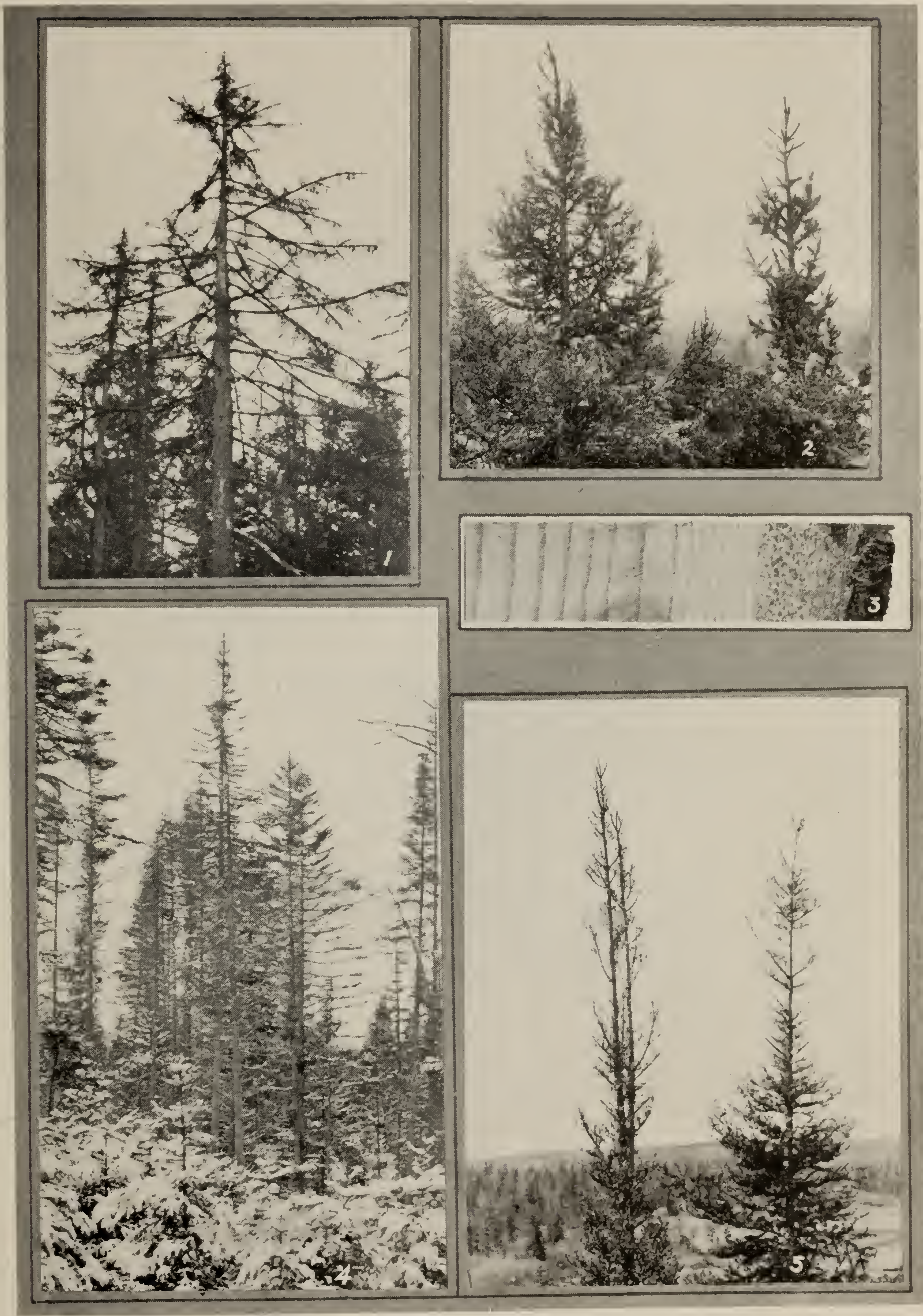
Fig. 1.—Photograph of red spruce in spring of year just before bark-beetle attack to illustrate shedding of old foliage not removed by caterpillars. See detail in fig. 1, plate VIII.

Fig. 2.—Two black spruce tops to show condition after four years budworm feeding. All or part of new growth removed each year. This gives an idea of the appearance of tree (fig. 1) before the needles were shed.

Fig. 3.—Section from near base of balsam attacked by *Pissodes* and dying in 1921. Large ring 1910 indicates first feeding. Note failure of tree to regain normal increment and no wood laid on in 1921.

Fig. 4.—Showing appearance of clump of balsam and several spruce after defoliation. Photograph by M. P. Dunn.

Fig. 5.—Two balsam tops after four years budworm feeding. Note that much more of old foliage removed than in case of spruce, fig. 2.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3
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5

PLATE VIII

Fig. 1.—Single branch from red spruce (same tree as fig. 1, plate VII, taken in the spring of 1922. It was later attacked by barkbeetles the same summer. Note shedding of all older needles and growth of slender branchlets of previous summer.

Figs. 2, 3, 4.—Illustrating one year's feeding by budworm larvæ when very abundant on caged trees. This was an attempt to reproduce conditions at the height of an outbreak. Figs. 2 and 3, red spruce; fig. 4, white spruce. Note that only the foliage of current years growth was consumed although many larvæ were concentrated in the cages.


1.
No. 11
2
3
N. 10
4.

PLATE IX

Photograph to illustrate condition of (black) Spruce Flat Type, some ten years after the budworm outbreak. The dead stubs and broken tops are typical of many miles of this type when composed of a high percentage of balsam. Photographed by Mr. Thomas Nesbitt, Price Brothers, Limited.

PLATE X

Photograph illustrating protection of hardwoods (white birch and some poplar) on understory of conifers (balsam, white and black spruce.) This stand, twenty-five years of age, covers a large burn and was taken within a short distance of the stand illustrated by plate IX. Photographed by Mr. Thomas Nesbitt, Price Brothers, Limited

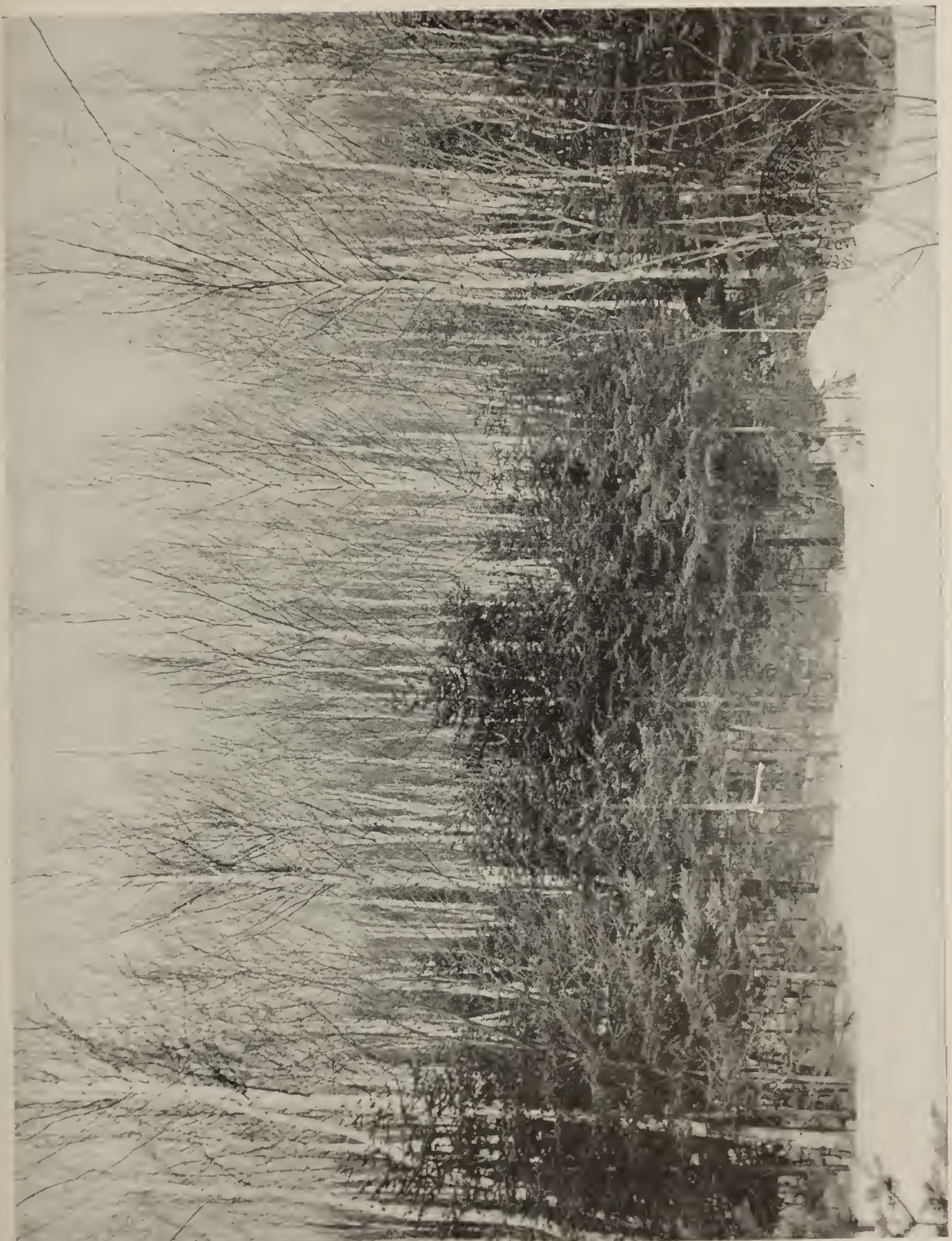
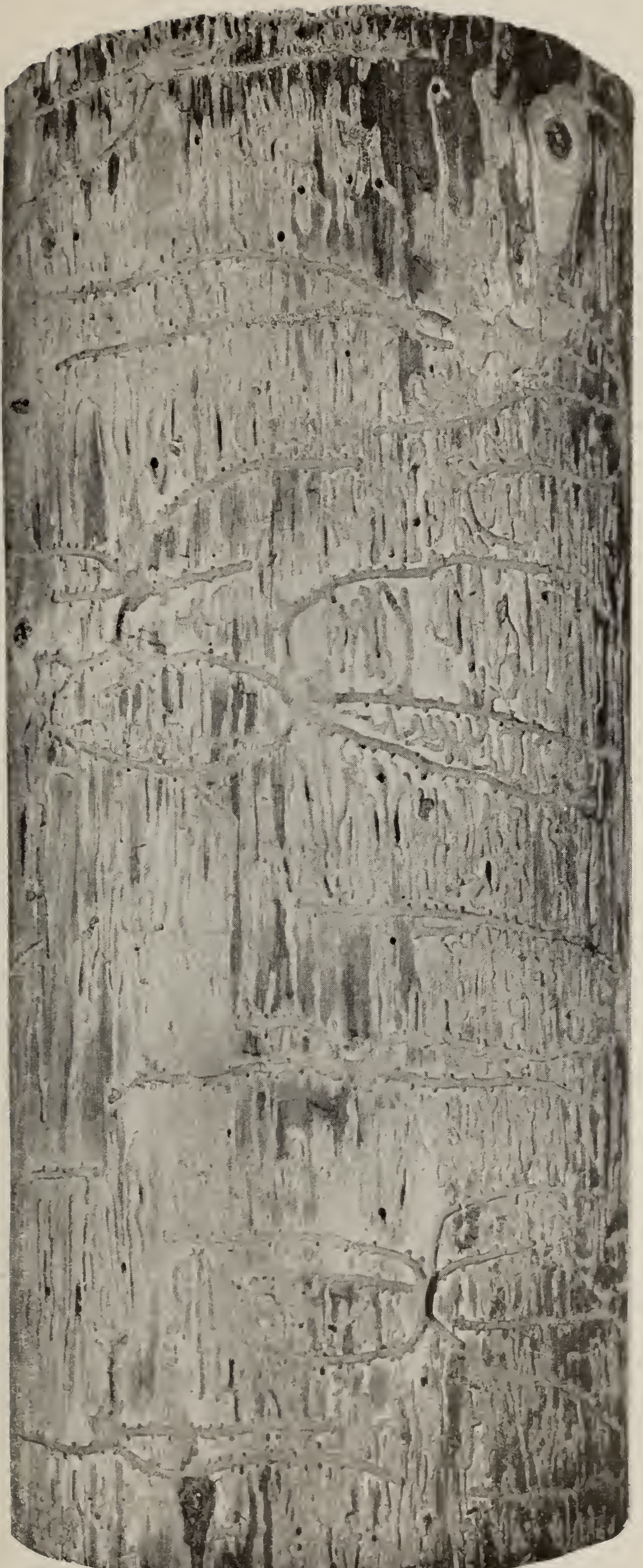


PLATE XI

FIG. 1.—*Pityokteines sparsus* Lec., brood galleries and larval mines on wood surface of balsam.

FIG. 2.—Section from spruce near Bathurst, N.B., showing budworm outbreaks in 1806, 1878 and 1914 The 1878 outbreak is not well defined on spruce in this region but shows typically on balsam and hemlock. The rings after 1914 did not show clearly on the photograph and are intensified on the left margin of the strip. Note wide ring followed the fourth year by narrow ring.




1914
1878
1806

PLATE XII

FIG. 1.—*Pissodes dubius* Rand. larval mines on inner surface of balsam bark. Not quite completed. Note mines radiating from egg punctures.

FIG. 2.—*Monochamus marmorator* Ky., larval mines under bark of balsam. Note transverse character as compared with plate XIII, *M. scutellatus* Say.

Plate XII

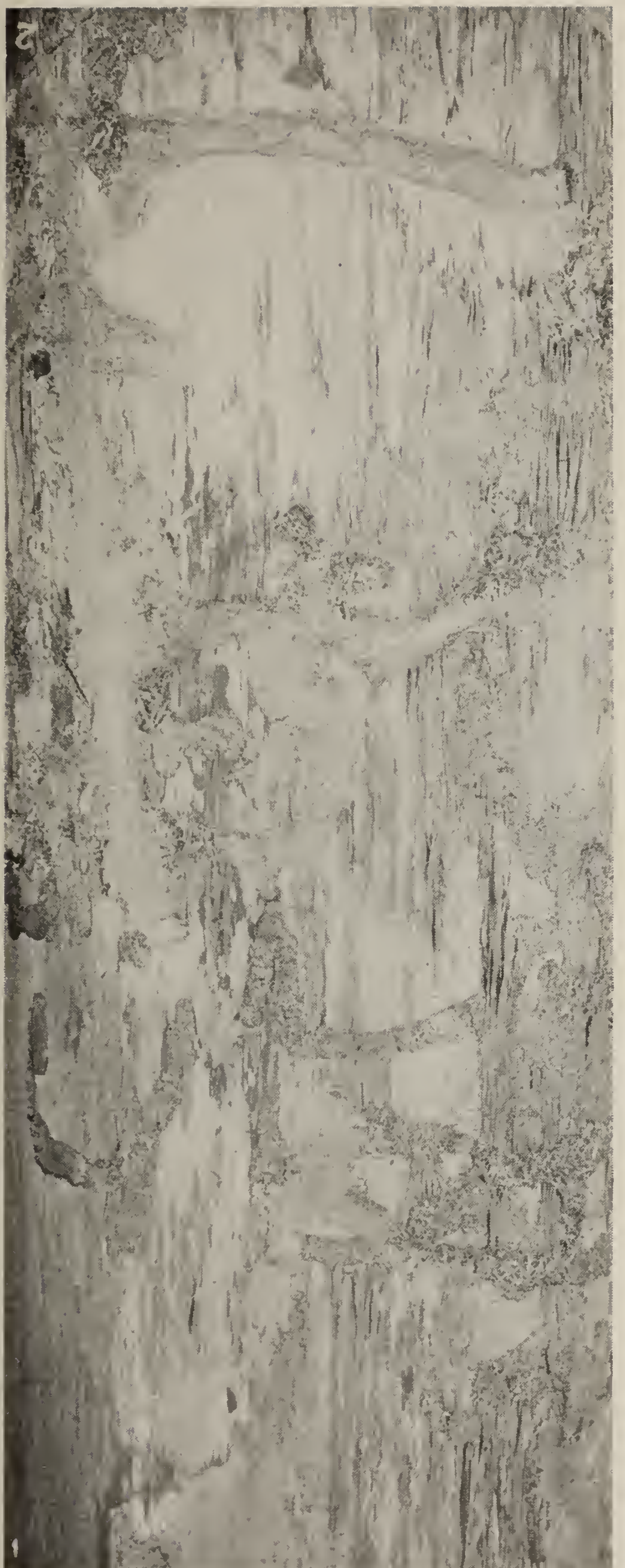


PLATE XIII

Monochamus scutellatus Say., larval mines in spruce showing scarring of wood surface and entrance holes into wood.

PLATE XIV

Monochamus marmorator Ky., egg scars showing characteristic pitch flow from wounds.

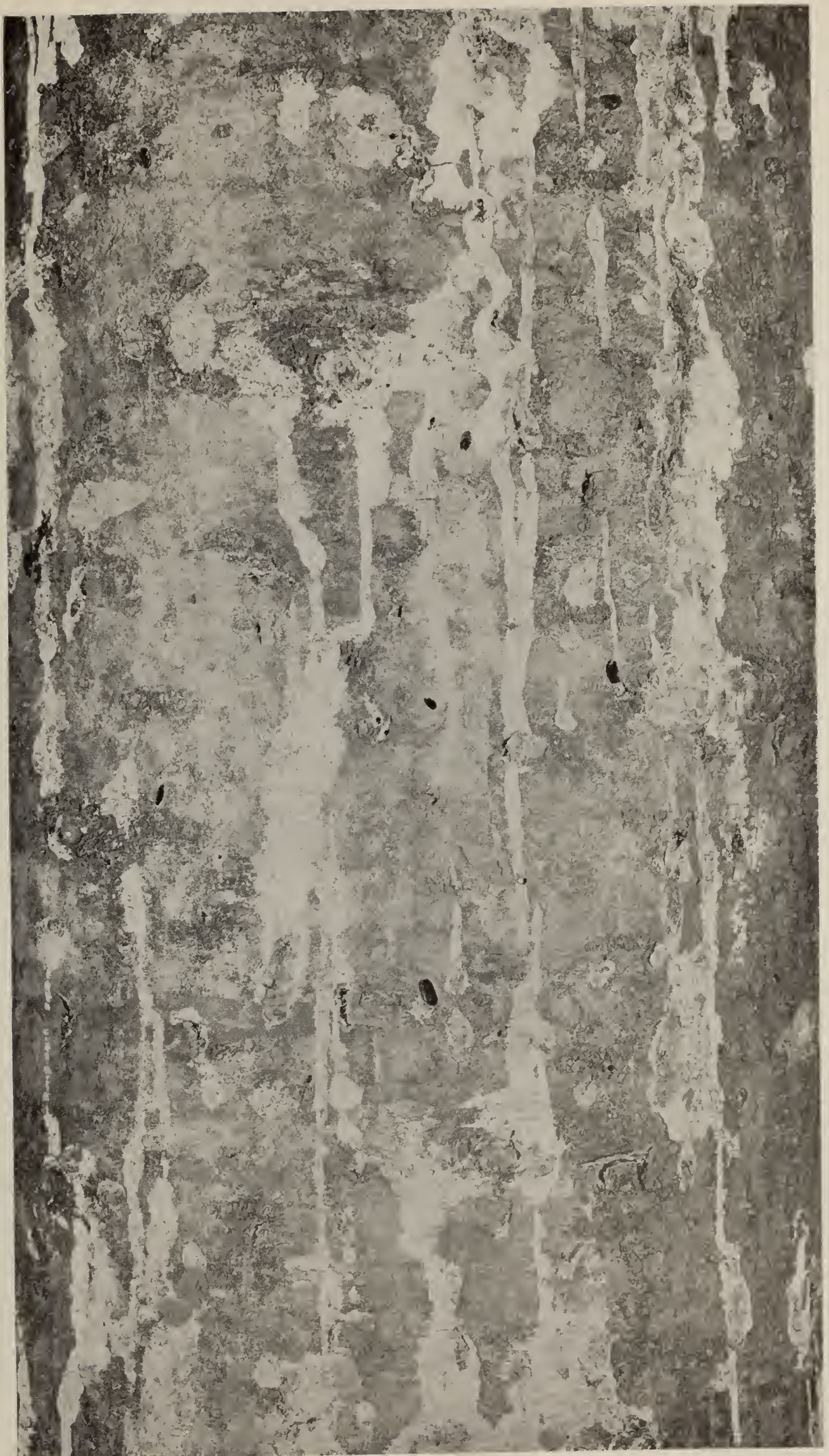


PLATE XV

Figs. 1, 2, 3.—*Monochamus marmorator* Ky., feeding on balsam twigs. Fig. 3 illustrates fresh feeding on underside of branch and needles. Fig. 1, healed scars. Fig. 2, dead twig with light red foliage on left, green twig on right.

Figs. 4, 6.—*Monochamus marmorator* Ky., eggs on under surface of bark and egg scars on surface.

Fig. 5.—*Monochamus scutellatus* Say., two egg scars on bark to show comparatively smaller size as compared to those of *marmorator*. The larger oval hole is made by the larva to expel frass.

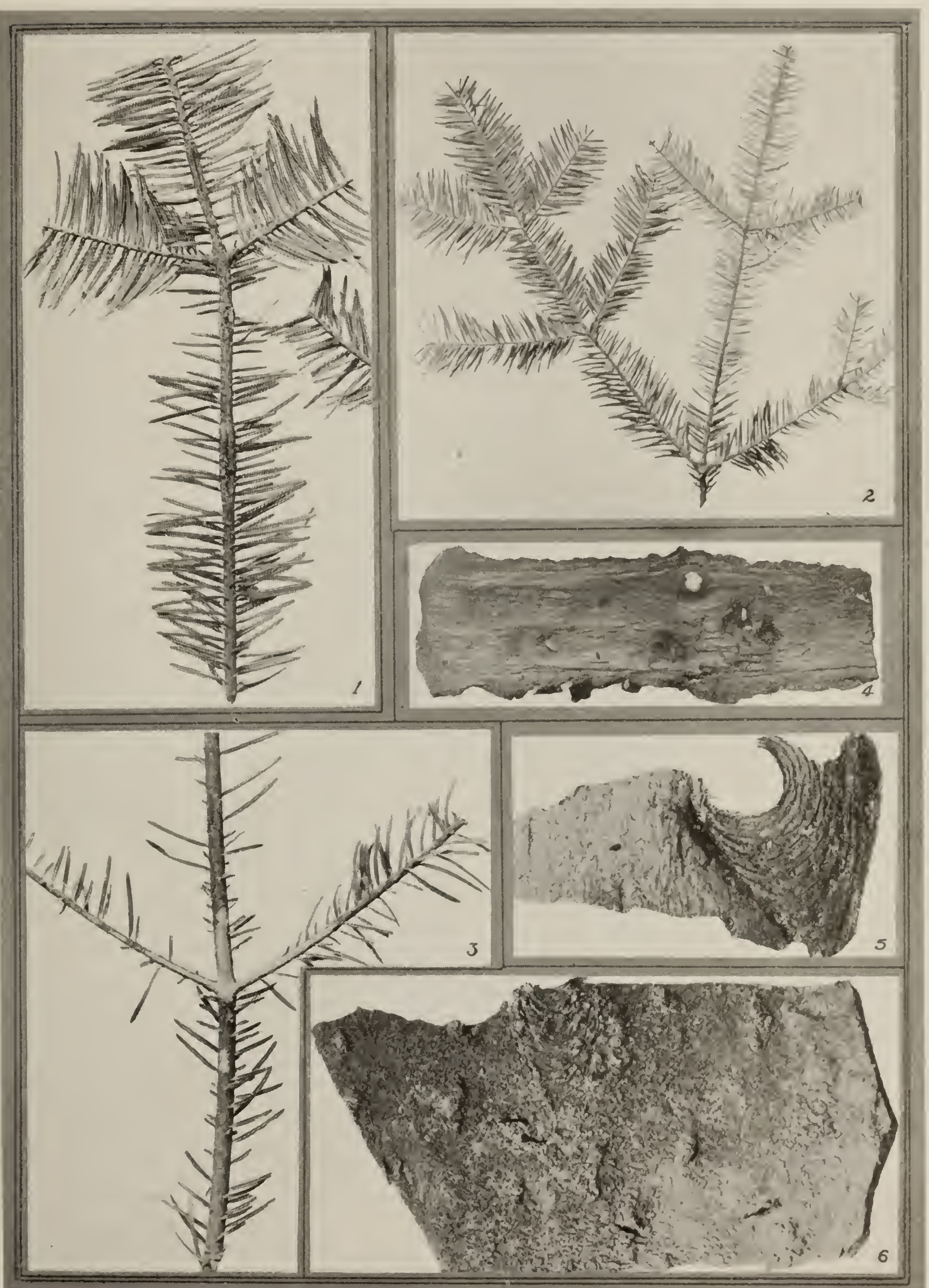

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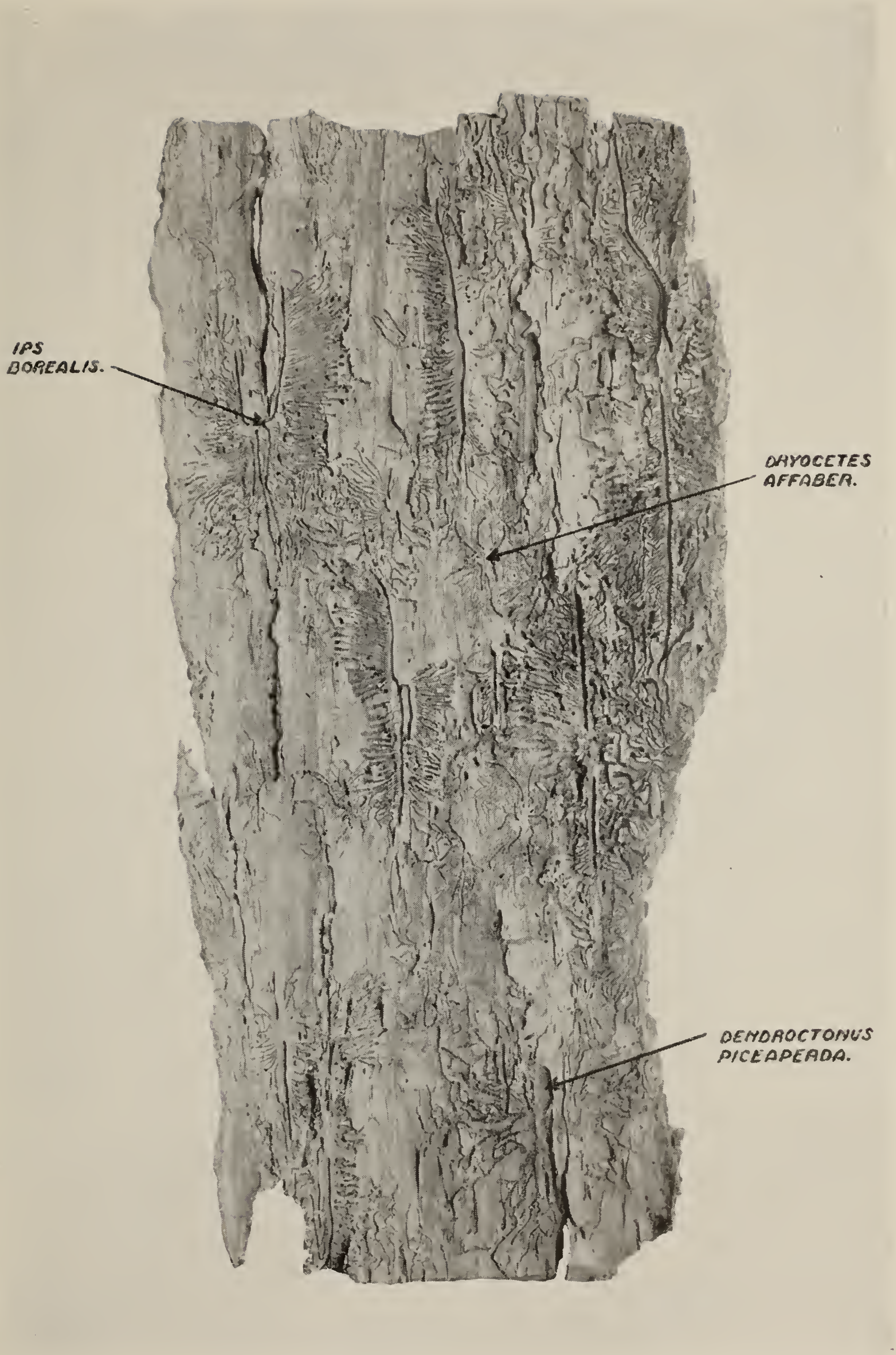
PLATE XVI

Ips borealis Sw., brood galleries and larval mines on inner face of spruce bark. X$\frac{1}{3}$.



Egg-tunnels and larval mines of *Ips* and *Dryocetes* on the inner face of spruce bark.

PLATE XVII

Dendroctonus piceaperda Hopk., larval mines on inner surface of spruce bark. X$\frac{1}{2}$.

PLATE XVIII

FIG. 1.—Second stage budworm larva entering black spruce bud before it opened.

FIG. 2.—Second stage budworm larva entering black spruce bud before it opened, from purchase of surrounding needles.

FIG. 3.—Egg mass of moth.

FIG. 4.—Hibernaculum on scale of aborted balsam cone.

FIG. 5.—First stage budworm larva greatly enlarged.

FIG. 6.—Diagramatic figure of *Pissodes dubius* work. Dark spots mark point where two groups of eggs were laid from which young larval mines radiate in the bast. Later these mines are extended beneath the bark and, gradually enlarging, terminate in the oval pupal cells, which are deeply scarred in the wood.

Plate No. XVIII

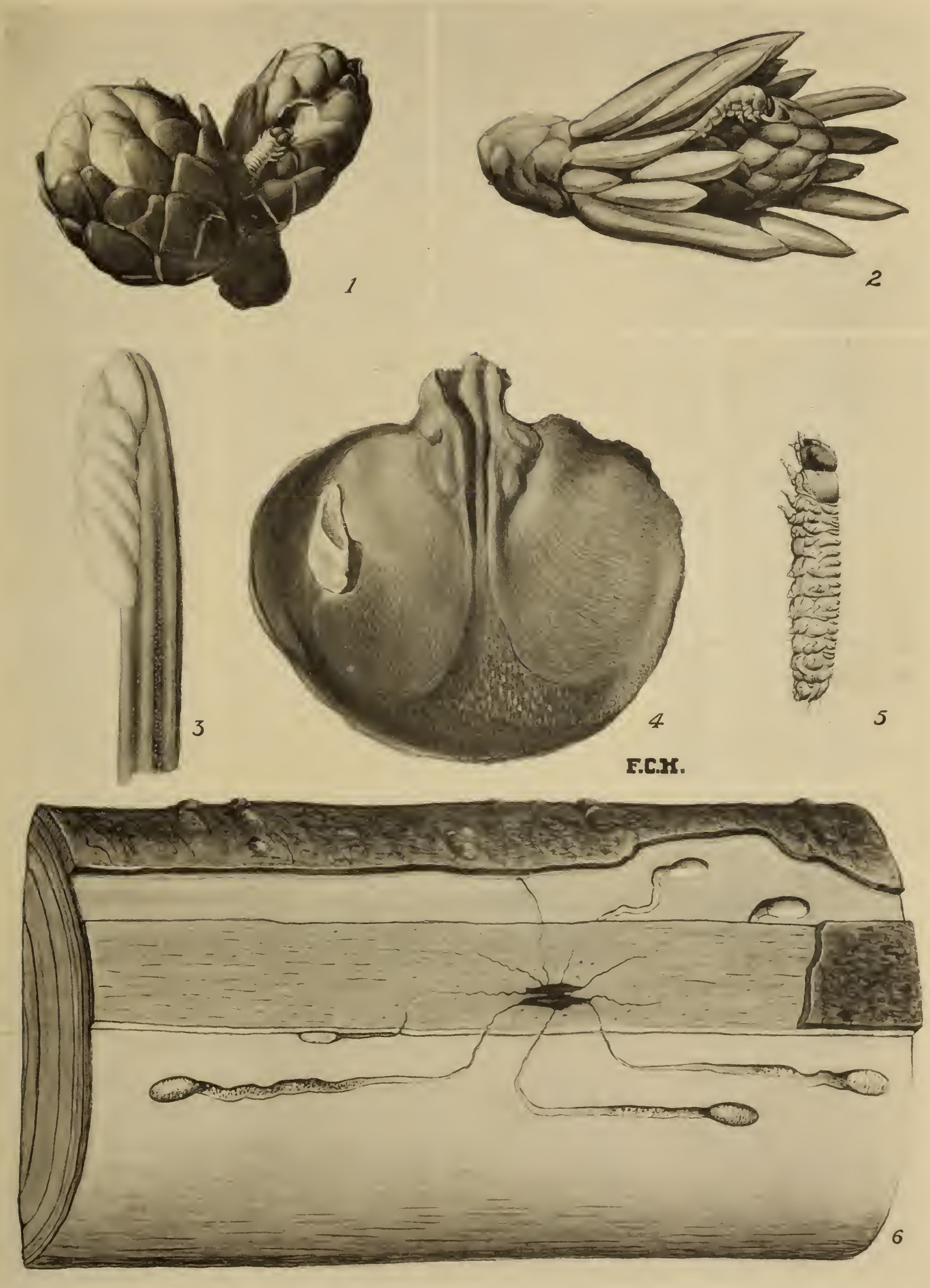


PLATE XIX

FIG. 1.—*Tetropium* sp., dorsal view of larva. X6.

FIG. 2.—*Tetropium cinnanopterum* Ky., dorsal view of last abdominal segment to illustrate difference in spines.

FIG. 3.—*Monochamus marmorator* Say, ventral view of pupa. X4.

FIG. 4.—*Monochamus marmorator* Say, lateral view of larva. X6.

FIG. 5.—*Monochamus marmorator* Say, dorsal surface of prothorax of larva.

FIG. 6.—*Dendroctonus piceaperda* Hopk., lateral aspect of larva. X15.

Plate No. XIX

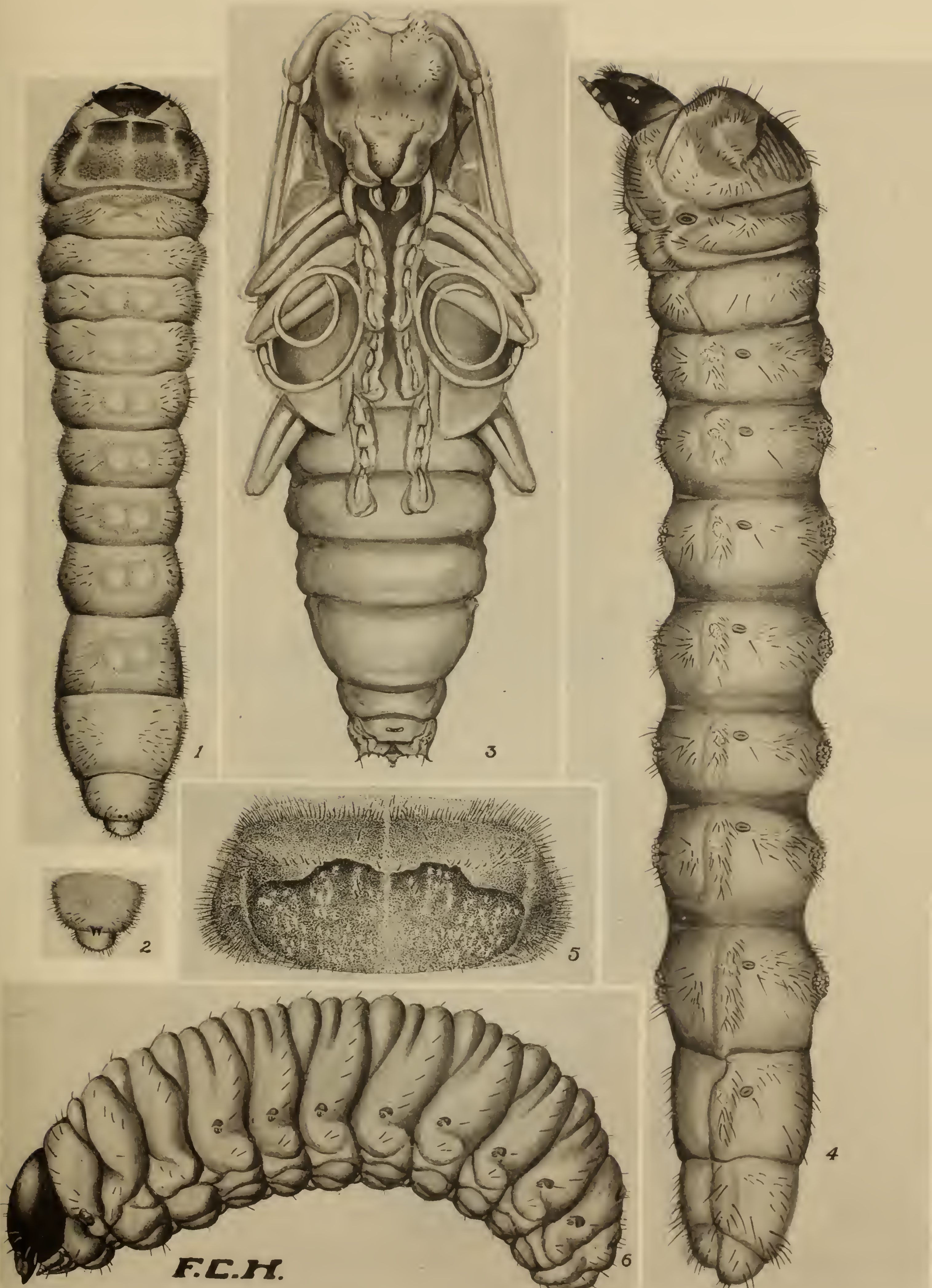


PLATE XX

Pissodes dubius Rand. Adult beetle. X20.

Plate No. XX

PLATE XXI

Fig. 1.—*Polygraphus rufipennis* Ky. (After Swaine). X25.

Fig. 2.—*Dryocoetes affaber* Mannh. (After Swaine). X35.

Fig. 3.—*Ips borealis* Sw. X18.

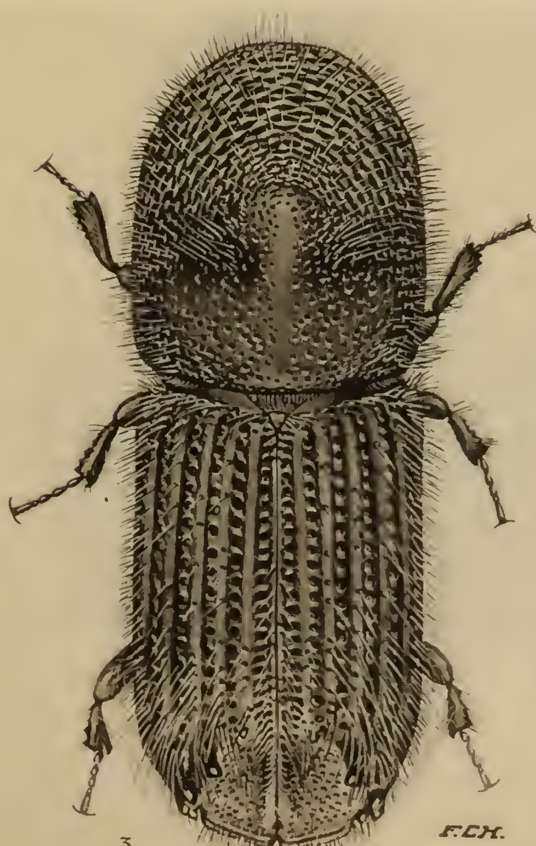
Fig. 4.—*Ips perturbatus* Eichh. X15.

Fig. 5.—*Ips perturbatus* Eichh., showing teeth of elytral declivity.

1

2

5



3

4

PLATE XXII

Fig. 1.—*Pityokteines sparsus* Lec. X40.

Fig. 2.—*Ips longidens* Sw. X30.

Fig. 3.—*Ips chagnoni* Sw. X20.

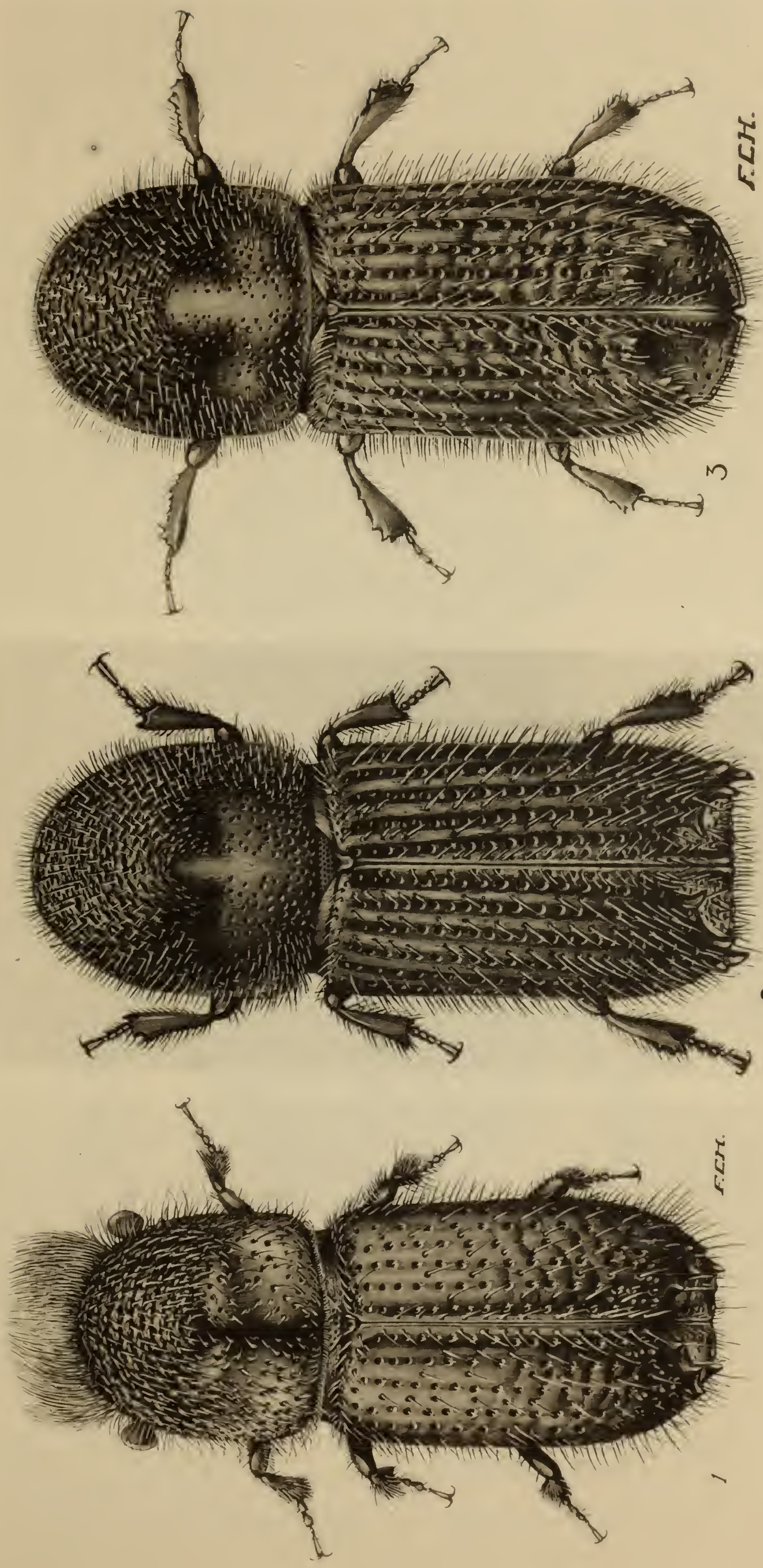

F.C.H.
3
F.C.H.
2
F.C.H.
1

PLATE XXIII

Dendroctonus piceaperda Hopk. Adult beetle. X20.

Plate No. XXIV

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