Technical Bulletin 142 April 1940

The Spruce Budworm in Minnesota

S. A. Graham and L. W. Orr

University of Minnesota
Agricultural Experiment Station

The Spruce Budworm in Minnesota

S. A. Graham and L. W. Orr

University of Minnesota
Agricultural Experiment Station

Accepted for Publication, February 9, 1940

CONTENTS

The Spruce Budworm in Minnesota[1]

S. A. GRAHAM[2] and L. W. ORR[3,4]

MINNESOTA forests have suffered repeatedly from the attacks of various insects, but of all these outbreaks the most disastrous, at least from the standpoint of volume of timber killed, have been those caused by the spruce budworm, *Cacoecia fumiferana* (Clem.). To call this defoliator the spruce budworm is really not logical because in spruce-fir forests its favorite host tree is balsam fir, and spruce is a second choice. Nevertheless, because the name is so well established through long usage, it seems inadvisable to attempt to change it now.

The spruce budworm is a native insect that is always present in the northern coniferous forests. For years it may be so scarce that it is seldom seen, but eventually, under favorable conditions, the population may increase tremendously and an outbreak results. Outbreaks have occurred in the past at intervals of from 40 to 70 years. Such an interval represents the period required for a generation of balsam fir to reach a dominant position in the forest stands.

Over vast areas repeated budworm outbreaks have destroyed inestimable quantities of timber. In some localities where outbreaks have been most severe, practically all the balsam fir and much spruce have been killed either by defoliation or by exposure and windthrow following the opening of the forest by the budworm killing.

The last series of outbreaks in Minnesota started in Koochiching County in 1912 when many individual trees were heavily

[1] The studies on which this bulletin is based were conducted through the cooperation of the University of Minnesota, the Bureau of Entomology and Plant Quarantine and the Forest Service of the United States Department of Agriculture, and the Minnesota Forest Service.

[2] School of Forestry and Conservation, University of Michigan, formerly of the Division of Entomology and Economic Zoology, University of Minnesota.

[3] Bureau of Entomology and Plant Quarantine, United States Department of Agriculture, formerly of the Division of Entomology and Economic Zoology, University of Minnesota.

[4] Later a more detailed analysis of the results of the budworm outbreak in Minnesota will be prepared by the junior author. Because of the temporary interruption of the study, it seems desirable to prepare a brief statement prior to the completion of the more detailed work so that the results to date may be available for use.

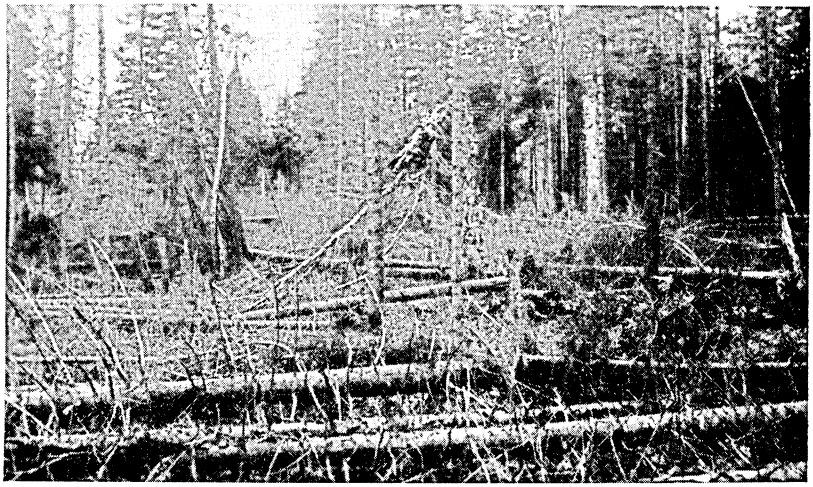

FIG. 1. THE REMAINS OF A TYPICAL BALSAM FIR STAND IN COOK COUNTY, MINNESOTA, FOLLOWING THE SPRUCE BUDWORM OUTBREAK

Balsam fir trees killed by defoliation are soon weakened by butt rot and fall over, causing a serious increase in fire hazards and adding greatly to the difficulty of fire fighting.

defoliated. In the following year, 1913, general heavy defoliation occurred in those stands predominantly balsam fir and spruce. This defoliation extended throughout much of Koochiching and parts of St. Louis and Lake counties. Later, in 1918, general defoliation occurred in eastern Lake and western Cook counties, and still later, 1923, the eastern part of Cook County became involved.

The most severe injury occurred in the areas where the outbreak started in 1912 and 1913. There the forest type was predominantly balsam fir interspersed with smaller quantities of both white and black spruce. Most of the large balsam fir and much of the spruce were killed outright by the defoliation (Fig. 1). This killing opened up the stand to such an extent that much of the spruce that had survived defoliation blew over (Fig. 2).

The forests in Lake and Cook counties, where defoliation began in 1918, were somewhat less severely injured than the forests attacked in 1912 and 1913. Although less spruce succumbed, the balsam fir of merchantable size was almost completely destroyed. Still farther toward the east, where the first defoliation occurred in 1923, practically no spruce and very little balsam fir died. Why each successive wave of infestation was

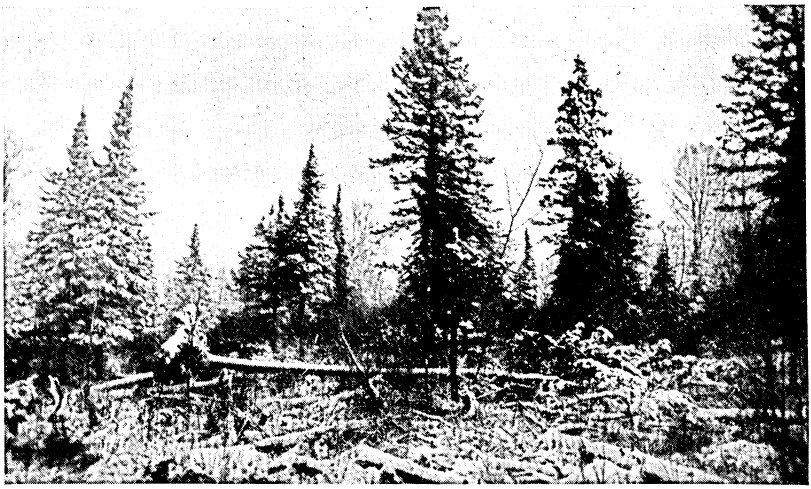

FIG. 2. WINDTHROWN WHITE SPRUCE IN A STAND IN LAKE COUNTY, MINNESOTA, OPENED UP BY THE SPRUCE BUDWORM

weaker than the preceding one is not entirely clear, but it appears that natural forces of control were playing a part in an increasing degree.

AMOUNT OF DAMAGE

Estimates of damage caused by the budworm are based on the percentage of trees killed on sample areas. No adequate general survey was possible.

Data obtained on a large number of one-tenth acre sample plots in Koochiching, St. Louis, Lake, and Cook counties indicate that between 85 and 90 per cent of the merchantable volume of balsam fir was destroyed over most of this area. Although no accurate estimates of the volume of balsam fir were available, it seems likely that just prior to the outbreak there was a total of nearly 30 million cords in northern Minnesota. On the basis of the above estimate the destruction of balsam fir alone probably exceeded 20 million cords, a stupendous volume of wood. No attempt has been made to estimate the loss in spruce because the injury to that species varied so much from place to place that our data are not adequate for generalization. All that can be said is that losses were heavy in some places, especially from windthrow and other effects of exposure following the outbreak, and in other places were very light.

In considering the amount of damage caused by the spruce budworm, it must be remembered that the greatest injury was to balsam fir, a tree which at that time had a very low commercial value. Furthermore, much of the timber killed was inaccessible and would not have been utilized for many years even if it had remained alive. In fact, much of the balsam killed was mature or over-mature and was rapidly passing into the period when decadence would have exceeded annual growth. For these reasons the actual loss to the wood-using industries was much less than would at first appear.

FIG. 3. A YOUNG STAND OF BALSAM FIR GROWING UNDER ASPEN

Such stands will soon become susceptible to an outbreak of the spruce budworm.

Since 1912, however, conditions have changed a great deal. Most of the formerly inaccessible areas can now be reached conveniently, and balsam fir is now in demand for pulpwood. It is, therefore, important that we use every possible means at our disposal to prevent or ameliorate the effects of future disastrous outbreaks of the budworm. The loss occasioned by such an outbreak today would be much more serious economically than was a similar amount of damage 25 years ago.

Although the budworm has been quiescent for more than a decade in the fir and spruce forests of the North, it is still a serious menace to these forests. The stage is now being set for another outbreak. Many areas occupied by balsam fir stands that were unsuitable for the budworm

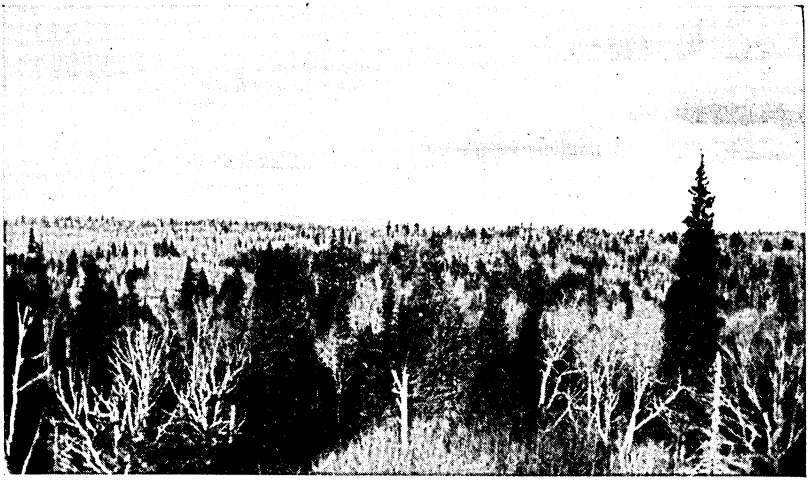

FIG. 4. MATURE BIRCH, ASPEN, AND SPRUCE LEFT AS AN OPEN STAND FOLLOWING KILLING OF THE BALSAM FIR BY THE SPRUCE BUDWORM IN LAKE COUNTY, MINNESOTA

The birch and aspen have rapidly deteriorated and some of the spruce has been windthrown.

in 1912 to 1918, and therefore escaped injury, are now becoming suitable (Fig. 3). There is so much budworm-susceptible timber developing that an outbreak seems inevitable. It is believed, however, that steps can be taken to check its intensity and, to a certain degree, reduce its unfavorable economic effects. These will be discussed in the section on control.

LIFE HISTORY AND HABITS OF THE BUDWORM

In order to discuss intelligently the activities of the budworm, it is necessary to consider briefly the life history and habits of the insect.

The adults are inconspicuous grayish-brown moths with a wing spread of about three quarters of an inch. They emerge in Minnesota during the latter half of July. The moths congregate on the balsam fir and spruce and seem to prefer to rest and lay their eggs on the upper parts of the trees. The moths often occur in such large numbers that in their flight they resemble a cloud of grayish snowflakes whirling around the treetops.

The eggs are deposited on balsam fir or spruce needles in clusters of from 20 to over 100. The clusters are green, elongated, and tapering, and the individual eggs overlap one another like the

shingles on a roof. The eggs hatch late in July or early in August, and the tiny larvae crawl about in search of convenient shelter under lichens or in bark crevices. Then each larva spins a thin silken web or hibernaculum. Studies in the Lake states have failed to show any indication that the larvae take food prior to hibernation.

In the spring, when the buds of the balsam fir are expanding, the larvae emerge and break their long fast by feeding upon the fresh and tender needles. During the early stages they can feed only upon fresh foliage; therefore, at that season of the year, they are forced to feed almost exclusively upon balsam fir or in some cases upon white spruce because the black spruce, which is by far the most common spruce in northern Minnesota forests, does not start growth until after the larvae have been out of hibernation and demanding food for one or two weeks. White spruce opens its buds earlier than the black spruce and about the same time as does balsam fir. It is, therefore, more suitable for early feeding than black spruce, but because its foliage hardens very quickly, it does not provide as suitable food later in the feeding period as does either the balsam fir or black spruce. Feeding conditions are unfavorable during the first part of the season for larvae hatching from eggs deposited on black spruce. Such larvae can find suitable food only by burrowing into the buds, which provide a very limited supply. Because of this limitation many of them drop on threads of silk and may be blown by the wind to nearby trees. Under such conditions the chance of larval mortality is high.

The emergence of the budworm from hibernation at the same time that the balsam buds open and the requirements of the small larvae for an adequate supply of fresh tender tissue undoubtedly explain the resistance of pure stands of black spruce to injury because in such stands there is not enough early-season food to support a large budworm population.

Ordinarily the larvae do not move about much during the feeding period as long as an adequate supply of suitable foliage is available. When, however, all the new foliage on one tip has been destroyed, the larvae on that tip either move to an adjacent tip or drop on threads and are blown to other tips, perhaps on another tree. After the early stages they are not quite so exacting in their food requirements and feed freely upon both spruce and balsam fir.

As they work they cover themselves with a light silken web which holds the needles together. Usually, instead of eating an entire needle, a larva will merely sever the needle at the base, leaving the tip hanging in the web. These severed needles turn brown and give a scorched appearance to the defoliated tree.

The feeding period of the larvae is short, three to four weeks being, as a rule, sufficient for development. They then transform to the pupal stage upon the tips where they have fed. The pupae and later the pupal skins are held fast to the tips by hooks, on the caudal end of the body, which are entangled in the silken webs that were spun by the feeding larvae. The cast pupal skins may in some instances persist on the trees for several months after the emergence of the moths. The adult moths emerge during the latter half of July and, after mating, begin to lay eggs. Thus the life cycle is completed.

EFFECT OF AN OUTBREAK ON VARIOUS HOST SPECIES

When the food requirements of the insect are considered, the reason becomes apparent why balsam fir is the most susceptible of any tree in Minnesota to budworm attack. The emergence of the larvae from hibernation is synchronized with the bursting of the buds, and, because the foliage remains soft and succulent for a long period, the larvae find suitable food throughout the season on this host. Movement from tree to tree, except where excessive defoliation has occurred, is therefore unnecessary when the insects attack balsam fir. Conditions are ideal for a maximum rate of multiplication in a pure forest of this species because there is an abundance of suitable food and little loss of larvae due to transfer from one host to another.

Neither white spruce nor black spruce in pure stands is a suitable incubator for a budworm outbreak because the former does not provide suitable late-season food and the latter does not provide an adequate amount of food early in the season. Thus these trees are immune to serious injury except when growing in mixture with balsam fir. During periods when the budworm is abundant, both white and black spruce growing among firs may be severely defoliated and killed. More often, however, the loss in spruce is the result of indirect effects. Usually the spruce is less severely defoliated than the balsam fir, and much of it would recover if it were not for the death of the balsam fir and

the consequent opening of the stand to such a degree that much spruce is injured by exposure or may be windthrown. In some other instances secondary beetles or fungi may attack and kill the spruce that has been weakened by defoliation.

The budworm does not confine its attack to firs and spruces but is also an enemy of pine. Observations and experiments indicate, however, that the outbreaks on pine are caused by a biologic race of the insect that does not attack fir and spruce except when small trees of these species occur as an understory in heavily defoliated stands of pine. There are no records of budworm outbreaks which have developed in stands of pine and spread to adjacent stands of fir and spruce, or vice versa. Several outbreaks on jack pine have occurred in Minnesota, Wisconsin, Michigan, and Ontario since 1923, and in some areas considerable amounts of timber have been killed.[5] The budworm as a pine insect will not be discussed in detail.

THE COURSE OF AN OUTBREAK

Outbreaks of the fir-spruce form of the budworm invariably arise in areas where the forest is predominantly balsam fir that averages 4 inches or more in diameter. Young fir or spruce stands, trees overtopped by aspen, birch, or pine, and balsam fir trees in forests that are predominantly hardwood or pine are seldom severely defoliated even during an outbreak in adjacent stands. Outbreaks may be expected in extensive areas of susceptible timber as soon as other conditions also become favorable.

Usually, if not invariably, outbreaks result from the rapid multiplication of the insect within the general locality involved and not by migration from an outside point. The tremendous potential rate of multiplication is sufficient to account for the sudden appearance of the insect in forests where it has been only an inconspicuous resident for many years. A single female may lay more than 360 eggs, a reproductive rate sufficient to permit almost a 200-fold rate of increase. Actual increases of 100-fold have been observed in the forest. Therefore under favorable conditions the budworm may, within a period of 2 or 3 years, build up from a scattered population to outbreak proportions.

The first indication of an outbreak is the partial defoliation of scattered individual trees. This is followed by infestation of tree

[5] S. A. Graham. *The Spruce budworm on Michigan pine.* University of Michigan, School of Forestry and Conservation, Bulletin No. 6, 1935.

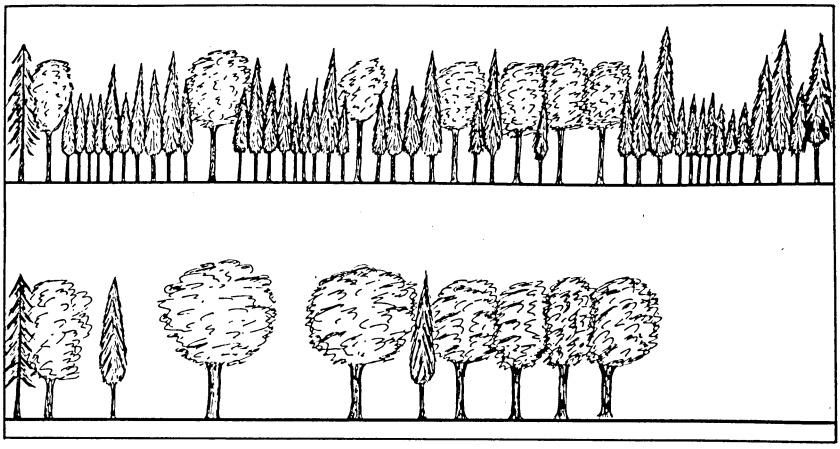

FIG. 5. EFFECT OF BUDWORM INJURY ON A STAND CONTAINING A HIGH PERCENTAGE OF BALSAM

This represents a plot of one-tenth acre on the Wales Branch of the Duluth and Iron Range Railroad. The trees are drawn to show as nearly as possible their relative size and position in the stand. The upper row represents conditions previous to the budworm outbreak; the lower row, conditions about 10 years later.

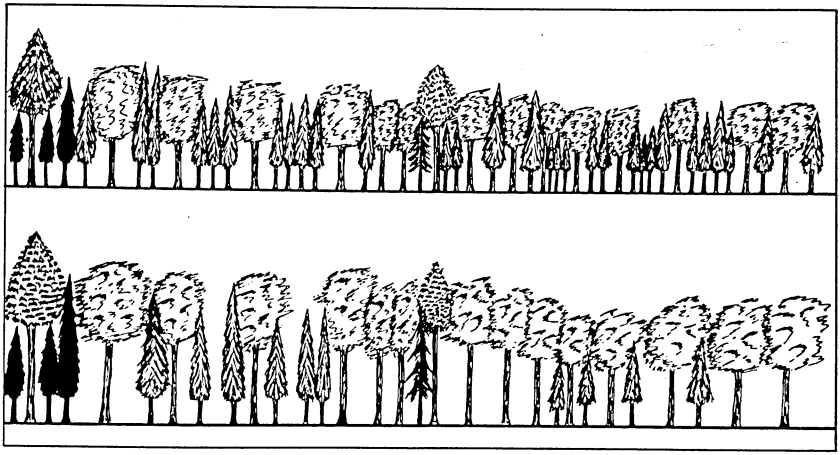

FIG. 6. EFFECT OF BUDWORM INJURY IN MIXED STANDS

This one-tenth acre plot was within 2 miles of the one shown in Figure 5. It is improbable that the insect would ever have become epidemic in such a stand had it not been for nearby pure or nearly pure stands.

LEGEND FOR FIGURES 5 AND 6

Conical shaded=Balsam Conical solid=Cedar
Broadly conical=White Pine
Drooping branches=Spruce Rounded crown=Birch

groups and then by general defoliation. After three successive years of defoliation the trees begin to die rapidly. This is especially true of balsam fir. Spruce is usually less severely defoliated and is likely to survive longer. The rate of dying depends upon various factors, particularly the site conditions under which the trees are growing and the proportion of foliage destroyed.

Complete defoliation would kill either fir or spruce in a single season but, as previously pointed out, the budworm feeds mostly upon the foliage of the current year, especially in the case of spruce. For this reason the trees can endure several years of injury.

Each year the trees put forth a smaller amount of foliage, and each year the budworm increases in number until the larval population exceeds the amount of suitable food present. Then the insects are faced with starvation. Their capacity to reproduce rapidly becomes their undoing, and starvation on a wholesale scale follows. At such times in their wanderings in search of food the millions upon millions of larvae, each spinning a thread of silk as it crawls about, may cover the tree branches, trunks, stumps, and even the ground with a mantle of silk. As a result of starvation, and to a lesser degree the activities of parasites and predaceous animals, the budworm population is almost exterminated, and for many succeeding years this insect is a rare inhabitant of the forests.

After defoliation has ceased, the trees that are very severely injured continue to die for several years. The others recover unless they are attacked by secondary organisms such as bark beetles or fungi. Many of the survivors have their tops killed, and these stag-headed trees stand for years as mute reminders of the budworm outbreak.

EFFECTS OF DEFOLIATION

A more detailed description of the effects of defoliation on balsam fir may be of interest. Following the first season of defoliation most of the branches form buds and produce foliage the following spring. Careful examination, however, discloses many dead twigs, especially toward the top of the trees. Following the second year of injury the dead twigs become more conspicuous and the tops begin to die. After the third year the heavily defoliated trees put out very little new foliage although the old needles may remain green.

These visible effects on the crown are accompanied by concealed effects beneath the bark and in the root system. The destruction of foliage prevents the synthesis of food materials, and when the reserve supply is exhausted, the tree starves. This results in injury to the root system. The root hairs and then the fine feeding rootlets die. When the injury has reached this stage, the tree is usually doomed, although it may still have some green foliage.

The reduction of photosynthetic activity also affects the formation of the annual layers of wood. These hidden effects of defoliation were first determined by Craighead[6] and his associates working in eastern Canada and have been verified in the study of the Minnesota outbreak. The effect of defoliation upon the annual rings is especially important because it makes possible the accurate determination of the first year of severe defoliation even after the outbreak has passed.

In the first year of defoliation the tree draws upon its supply of reserve food and growth continues, but in an abnormal manner. Apparently the defoliation and the resultant reduction in photosynthesis and transpiration disturb the normal translocation and use of food within the tree. Less wood than normal is produced on the upper part of the tree resulting in a ring at the top which is decidedly narrower than the ring of the previous year. In contrast, the ring laid down at the base is very slightly narrower or may even be wider than the previous year's growth.

The ring picture at the base of the tree shows successively narrower rings following the first year or two of injury. This reduction may continue until only partial rings are formed or growth ceases entirely and death occurs. If the tree recovers, the slow growth continues for a number of years and then, as new foliage and rootlets are developed to replace those lost, growth gradually increases until it again becomes normal.

During this period of reduced growth the tree is very susceptible to attack by secondary agencies. The balsam bark weevil, *Pissodes dubius* Rand., the balsam bark beetle, *Pityokteines sparsus* (Lec.), and the balsam sawyer, *Monochamus marmorator* (Kirby), are three insects that are particularly common at such times on balsam fir. Many trees that might otherwise recover are attacked and may be killed by these insects. Fungi that

[6] J. M. Swaine, F. C. Craighead, and I. W. Bailey. *Studies on the spruce budworm*, Canada Department of Agriculture, Bulletin No. 37, New Series (Technical), 1924.

cause root or heart rots often infect the weakened trees and cause much damage. There is considerable disagreement among forest entomologists as to the importance of these secondary agencies. Some attribute great importance to them, whereas others think that these species usually limit their attack to trees that have been defoliated so severely that they are doomed even without further injury.

Finally, the danger of windthrow in stands that have been opened up by the budworm is very serious (Fig. 2). This is especially true on the rocky and shallow soils that are common over much of the land in northeastern Minnesota occupied by northern coniferous forests. Many instances have been observed where the actual damage by the budworm, although relatively light, was sufficient to open the stand so that the greater part of the remaining fir and spruce was windthrown. In many places paper birch and aspen, growing with the balsam fir and spruce at the time of the outbreak, have been unable to endure the changed conditions and have rapidly deteriorated (Fig. 4).

TREE REPRODUCTION FOLLOWING BUDWORM OUTBREAK

A good stand of reproduction has become established on most areas following the great budworm outbreak. Because balsam fir suffered more from the budworm attack than did the spruces, it seemed reasonable to suppose that there would be an increased proportion of spruce in the succeeding forest. However, periodic counts of reproduction on sample plot areas made from 1925 to 1937 suggest that this probably is not true. Present conditions indicate that, where fire has not followed the budworm, there will be a larger proportion of balsam fir in the developing tree generation than in the original stands. This conclusion must, however, be regarded as tentative pending completion of these studies.

THE INCREASED FIRE HAZARD

Following the outbreak the dead trees soon rotted and fell. The result was a tangle of stems and tops covering the ground like giant jackstraws (Fig. 1). In places where there was a heavy stand of balsam fir prior to the outbreak the fallen tangle was so deep that a man standing on the ground would be completely hidden.

The fire hazard under such circumstances is great. Fire once started in such a tangle of dead and down timber is almost impossible to control. Several large and very severe fires have occurred in the budworm area in recent years, and the difficulty of bringing them under control has been greatly increased by the presence of this debris.

CAUSES OF A BUDWORM OUTBREAK

From the previous discussion it seems apparent that large areas occupied predominantly by balsam fir are necessary before the budworm can reach injurious numbers. Therefore, the forces leading to the development of this susceptible forest type are underlying causes of budworm outbreaks. There are, however, numerous instances of forests with a composition favorable to rapid budworm multiplication that are not immediately attacked. In fact, vast areas may be favorable for many years before an outbreak actually occurs. We must, therefore, conclude that in addition to the presence of favorable forest types other factors must also be favorable. Thus, the conditions leading to outbreaks may be divided into two groups: preparatory causes leading to the development of budworm-susceptible forests, and immediate causes that stimulate an outbreak at a particular time and place. The first group are better understood than the second.

The preparatory causes are either directly or indirectly concerned with the natural succession of plants. Every one who has watched any undisturbed piece of land has observed the never-ending series of changes that occur. New plant species appear and old residents disappear, representing stages in an orderly successional series. In the succession of forest trees each succeeding stage is clearly distinguishable and, if undisturbed, will gradually develop from one to another in orderly progression although this process may require a long period of time.

In northeastern Minnesota there are vast stretches of aspen, birch, and jack pine which form temporary types following forest fires. Various mixtures of red and white pine, northern white cedar, spruce, and balsam fir come in with and eventually replace these temporary species, provided the site is suitable and seed trees are present in the area. Where the white and red pines are present they assume dominance for a time but eventually give way to the more shade-tolerant spruce and balsam fir. Jack pine seldom succeeds itself without the aid of fire and is often followed

by spruce and fir. Outbreaks of the pine form of the budworm on jack pine may also hasten this conversion. Similarly, outbreaks of the forest tent caterpillar may hasten the conversion of aspen-birch stands to coniferous types.

Balsam fir is somewhat more tolerant than the spruces and, still more important, it is better able to become established where there is a deep layer of litter and duff. For these reasons it will, as a rule, ultimately win out over the spruces. Therefore, throughout much of northern Minnesota, natural succession is headed toward a climax type of forest that is predominantly balsam fir. The axe, fires, and insect outbreaks produce openings where the less tolerant trees can grow and thus tend to set back the course of succession. The browsing of animals, such as deer and snowshoe rabbits, has the reverse effect because they select young pines and hardwoods for their food in preference to fir and spruce.

From this it is evident that natural forces are tending toward the development of forests suitable for budworm outbreaks. For this reason it appears that man should attempt to direct the course of succession and maintain as far as possible the safer forest types. Too often he has failed to do this. The valuable trees such as pine and white spruce have been removed from mixed forests leaving the less desirable balsam fir to multiply. The economic reasons for such practices are readily appreciated although from an entomological standpoint the results have been disastrous.

Detailed studies of the immediate causes that stimulate outbreaks when forest composition is favorable to budworm growth have never been made directly. What we know of these causes has been learned indirectly. We know that the budworm is attacked by parasitic and predaceous insects and by disease-causing organisms. The larvae are fed upon by certain birds that nest in the northern coniferous forest such as the blackburnian and the chestnut-sided warblers. We know that other insects are affected favorably or adversely by weather conditions and suspect that the budworm is affected similarly. Undoubtedly during the period between the development of favorable forest types and the incidence of an outbreak these agencies individually and collectively hold the insect in check and preserve a condition of equilibrium in which the insect is able to maintain itself in small numbers, but is neither permitted to increase its population

materially nor is it completely exterminated. Obviously such a situation calls for a delicate balancing of forces within the forest.

When at some time a disturbing influence changes this condition so that a materially larger number of budworms reaches maturity, then the insect, because of its tremendously high potential rate of reproduction, is able to multiply rapidly, and, like a conflagration when once well started, the population of insects increases with growing momentum until the forest is consumed and the outbreak subsides for lack of fuel to carry it on.

Such a disturbance must have occurred just prior to 1912. No observations were made in the budworm areas at that time, and so we cannot be certain of what happened. The effectiveness of several agencies of control may have been reduced simultaneously, but observations in southern Minnesota, southern Wisconsin, and northern Iowa indicate a reduction of at least one limiting factor through the decimation of insectivorous birds.

Two such decimations occurred prior to the outbreak of the spruce budworm, one in 1907[7] and the other in 1910.[8] In the spring of each of these years unseasonably warm weather was followed by a freezing period with ice and snow. These cold periods came during the warbler migration. The insects that had been abundant earlier either returned into hibernation or died so that the insectivorous birds starved and succumbed to the cold by the thousands. Among the species that were severely decimated were the blackburnian and chestnut-sided warblers. We know that these birds are among the more important species that feed extensively upon budworm larvae, and that they normally nest in large numbers in the areas where the budworm outbreak occurred.

Such a loss during migration must necessarily have resulted in a corresponding scarcity of birds on the nesting grounds. Sherman records a scarcity of migrating warblers following 1907 and recovery to only 10 per cent of the former numbers by 1912. The budworm outbreak started in 1912. By 1925 the bird population had recovered. At that time the warblers were abundant on their nesting grounds and were observed feeding intensively upon the budworm larvae. It is possible that their activities prevented the 1923 budworm outbreak from becoming serious, but this is only a matter of conjecture.

[7] A. R. Sherman. "The Great Destruction of Warblers: an Urgent Appeal." *Bird Lore*, 17, 375-377. 1915.

[8] Personal observation of the senior author.

This circumstantial evidence indicates the possibility that the 1912 outbreak of the budworm in Minnesota was immediately precipitated by a scarcity of small insectivorous birds. The conclusion must not be drawn that this exact sequence of events always precedes an outbreak. A similar reduction in the number of predatory or parasitic insects, or a series of years when weather conditions are particularly favorable for the budworm might have a similar effect.

Once the reproductive momentum is started, the budworm's high fecundity carries it beyond the possibility of immediate control by animals with a lower reproductive capacity. Observations indicate that even insect parasites and predators, although they increase greatly in number during an outbreak, are no match for the budworm under such conditions and are able to destroy only about 10 or 15 per cent of the larvae and pupae. The proportion of the insects eaten by birds during an outbreak is insignificant because of the tremendous number of individual insects compared with birds.

When the number of the budworms is reduced by starvation, the budworm's ratio to parasites and predators changes in favor of the latter, and the percentage of budworms destroyed often reaches a very high figure of from 85 to 95 per cent. Thus the predatory and parasitic animals play a minor role during an outbreak, but at the end of the outbreak they effectively destroy most of the stragglers. Therefore, these friends of man serve him best during the years when the insects are relatively scarce. This is especially true of birds because the inherent population limitations of these animals prevent a sufficient increase to check outbreaks. Under normal conditions, however, when the insects are not excessive, the ratio of birds to the larvae upon which they feed is favorable for the control of the insects.

CONTROL OF THE SPRUCE BUDWORM

The usual recommendation for the control of defoliating insects is to spray or dust the foliage with a poison, usually lead arsenate or calcium arsenate. When the poison is carefully and thoroughly applied at the rate of 20 pounds or more per acre, a large proportion of the budworm larvae can be killed, and chemical control of infestations on valuable trees may be justifiable. Even under such conditions the results are not always satisfactory because the silken web under which the larvae feed often

prevents the poison from reaching the part of the foliage that will be eaten. Extensive operations in spraying or dusting for budworm control usually have been only partially effective.

Even if the treatment were effective, the high cost in comparison with the wood values to be protected would practically exclude its use in forests where commercial timber production is the objective. Therefore, although chemical control may have a valuable place for use in certain recreational areas and on ornamental trees, other control methods must be developed for use in commercial forests.

In inaccessible areas, such as parts of the wilderness area in the Superior National Forest, control probably would be impracticable. Periodic outbreaks at intervals of from 40 to 60 or 70 years must be expected in such areas, but, except for temporary injury to recreational values, the economic losses will probably be of minor consequence. The greatest danger in these places will be the serious fire hazard that will follow such outbreaks.

In commercial, timber-producing forests, silvicultural methods of budworm control are most effective. It has been shown in previous pages that some forest types are practically immune from injury whereas others are very susceptible. Therefore one objective of silvicultural procedure should be to produce and maintain budworm-resistant forests. In some places this can be accomplished easily; in others the value of the stand will not warrant expenditures for cultural operations prior to logging. In the following sections the practicability of cultural operations is assumed. It should not be overlooked, however, that the budworm hazard may be materially reduced by appropriate logging procedures in those instances where cultural operations are financially impracticable.

From the viewpoint of budworm control the ideal objective is to produce and maintain a forest in which balsam fir occupies a subsidiary position and combinations of other species such as pine, spruce, birch, and aspen predominate. It must be remembered, however, that balsam fir will establish and maintain itself in the North more easily than any other conifer, and that natural succession over much of that area tends toward a balsam fir forest. Therefore, the practical difficulties of maintaining a forest with a low proportion of fir must not be underestimated.

From the timber-management standpoint balsam fir is assuming increasing importance although it is still considered an in-

ferior species, largely because of its susceptibility to the budworm and to heart rot.[9] It has many desirable silvicultural characteristics such as the production of abundant seed at frequent intervals and the ability to establish and maintain itself under a wide variety of conditions. It grows fairly rapidly and responds well to cultural treatment. Because of the ease with which it can be grown, it is unfortunate that it is not of greater commercial value.

The success of forestry operations involving balsam fir will depend to a considerable extent upon the prevention of future budworm outbreaks. The authors realize that economic conditions must play an important part in determining how far it is feasible to go in applying intensive silvicultural treatments and also that the conversion of forest types is a long-time process.

Because of the great variation among present forest types and site conditions in northern Minnesota, no attempt will be made to suggest specific methods of handling them all. The recommendations that follow are based upon observations made under varying conditions over a period of years on a large number of sample plots throughout the budworm-infested region. There has been no opportunity to test them on a large scale. This should be done before they can be accepted without reservation. They are presented from the standpoint of budworm control alone and in actual application must be harmonized with other forest objectives. They are offered in the hope that they will be of assistance to the silviculturist and timber operator in formulating more detailed plans for treating specific tracts of timber.

Forest Types in which Balsam Fir Does Not Occur at Present

A definite effort should be made to prevent balsam fir from becoming established in stands where it is now absent. As indicated above, the natural succession in the forests menaced by the budworm in this area is leading toward an eventual balsam fir climax. Although the fir may not be present now, it is, in most cases, only a matter of time until it will invade such forests if nature is allowed to take its course. Frequently, this invasion of balsam fir comes about so imperceptibly that an understory of balsam has become established before its presence is realized. This situation is well illustrated in Itasca State Park, where the

[9] Frank Kaufert. *Heart rot of balsam fir in the Lake states, with special reference to forest management.* Minnesota Agricultural Experiment Station Technical Bulletin No. 110, 1935.

pines, birch, and aspen are now being replaced by balsam fir. It is important that those entrusted with the management of forest areas not yet invaded by this favorite host of the budworm should be on their guard against such invasion. In areas now free of balsam fir it appears desirable, from the standpoint of budworm control, to remove any trees of this species that may become established before they produce seed. Only in this way can the course of natural succession be checked.

Even though these balsam-free areas are relatively small in size, no reasonable effort should be neglected to keep them free. Such areas will serve to break up the forest and prevent the formation of continuous susceptible stands, reducing the danger of disastrous outbreaks in the forest as a whole.

Forest Types Containing Balsam Fir

The problem of handling forest types in which balsam fir is one of the component species is a complex one and will require the best efforts of the silvilculturist. Although the objectives are clear, mistakes in attempting to attain these objectives may occur. Nevertheless, the results of studies of the last outbreak are sufficient to form the basis for a reasonably safe course of procedure. Improvement of practices will naturally follow with experience.

First of all, a decision must be made as to the primary objective to be achieved through the management of each specific tract of land. This decision will be based on economic requirements, site conditions, and other nonentomological factors which need not be discussed here, but it should also take into consideration the relation of the budworm to forest types.

If the decision is to manage a given forest stand for the production of aspen, birch, or other hardwoods, the budworm problem ceases to exist for that particular area because such management would naturally involve the removal of shade-tolerant conifers, especially balsam fir. Where a market is available, it may be possible to sell some of this material as Christmas trees.

If, however, the production of conifers is to be the primary objective, budworm control should receive careful consideration in the formulation of silvicultural plans. Where the elimination of balsam fir is not feasible, as is the case in many localities in northern Minnesota, the protection of such stands from budworm outbreaks will require very careful planning and more intensive management than has been possible in the past.

It has already been pointed out that extensive budworm outbreaks are always associated with the development of large areas on which balsam fir over 4 inches in diameter occupies a predominant position in the upper crown canopy. If the development of these extensive stretches of susceptible forest can be avoided, it is believed that the danger of a general budworm outbreak will be very slight. Therefore, the treatment of this potentially dangerous type should lead to the development of a forest in which only relatively small, isolated blocks reach maturity at the same time. The hardwood competition can be utilized to retard the maturity of balsam fir in some places, while liberation and thinning operations hasten maturity in others. This will break up relatively uniform areas into blocks on which the balsam fir will be of different size classes in the present tree generation and improve the distribution of age classes in the future. In this way only a relatively small proportion of any extensive area will be in a budworm-susceptible condition at any one time.

Thus, on tracts of land where balsam fir is to be one of the major crop species, the suggested course of procedure is as follows:

1. Subdivide the tract into the smallest workable units following either the conventional land subdivisions or, preferably, topographic boundaries.

2. On one set of scattered units, usually those with the better stocked stands of balsam fir, cultural operations designed to encourage the early maturity of the balsam should be conducted. This would be accomplished by as complete a liberation of crop trees through thinning and cleaning cuts as is consistent with good forest practice. As a result, the trees on these units will be marketable at the earliest possible time.

3. On other units, also separated from one another, cultural treatments should aim at only a moderate stimulation of crop trees. In this way the balsam fir on these units will not reach a susceptible stage until after those units discussed above have been logged.

4. On still other units, in order to retard the maturity of the balsam as much as possible, no cultural work should be done.

In this way it appears that a relatively evenly developed forest may be converted to an unevenly developed forest in which

the balsam fir will reach maturity and may be cut at different times.

When other conifers such as pines and spruces are growing in mixture with balsam fir, aspen, and birch, the ideal procedure would be to eliminate the balsam and depend on the other conifers for the crop. This may be accomplished sometimes if the proportion of fir is small and can be removed in the course of cultural operations. When balsam fir comprises a considerable portion of the stand, it may be neither feasible nor desirable to attempt to eliminate it. Nevertheless, the other conifers should always be favored.

In stands that have reached merchantable size and in which the advance reproduction is not abundant, the removal of the balsam fir in a preliminary cut may be feasible. Such an operation should be conducted 10 years or more prior to the logging of the pines and spruce and should improve conditions for the reproduction of these more desirable species, particularly the spruce.

In this connection, one point especially should be kept in mind. Although the value of the aspen and birch in these mixed stands may be very little in terms of wood, these trees do have a very real value in terms of protection from the budworm. If it were not for the prevalence of these species throughout the greater part of the northern coniferous forests where the budworm is an important menace, there would be less possibility of satisfactorily controlling this insect. For this reason it is important that these species be maintained although their presence may not permit the maximum production of coniferous wood.

In mixed stands where the balsam fir attains a dominant position prior to merchantability, little can be done to reduce the immediate danger of budworm outbreaks. Cultural operations that will hasten maturity may be desirable in order to reduce the length of the budworm susceptible period. Here again in order to attain the greatest possible difference in the development of adjacent units the small-unit plan of operation is best.

In young stands where the balsam fir and the other conifers are still mostly overtopped by the hardwoods, there is the greatest opportunity for the application of budworm-control operations. If the number and distribution of spruce and pine trees are sufficient to provide a satisfactory crop of these species, cultural operations should be conducted to liberate crop trees with-

out liberating any of the balsam fir. In the course of these operations as much balsam fir as possible should be removed, especially the larger trees of that species, in order to reduce the amount of balsam-seed production.

Combinations of Spruce and Fir

The danger of destructive budworm outbreaks in mixed stands of spruce and fir varies greatly. It depends primarily upon the proportion of fir in the mixture although the quality of site sometimes exerts an important influence. On the best sites the trees seem to be better able to withstand the attack of the budworm than on the poorer lands. This difference in the response of the defoliated trees, depending on the conditions under which they are growing, has made it very difficult to determine the proportion of fir that is safe in spruce-fir mixtures.

Considering the strong tendency exhibited by the balsam fir to increase more rapidly than does the spruce in each succeeding tree generation, it appears desirable to use every practicable means to reduce the quantity of this species in the mixture. Spruce reproduction in areas where budworm outbreaks have occurred has, as a rule, been less successful than in cutover areas in the same localities. For this reason it seems likely that a preliminary cut of balsam fir not only would result in a reduction of the amount of seed dropped on the area by that species, but would also make conditions more favorable for the germination and establishment of spruce. The question of whether or not a preliminary cut of balsam fir is desirable will depend to a considerable degree upon the proportion of fir in the stand and the danger of windthrow in the event that the balsam is removed. Obviously an advance cut of balsam fir in stands of mixed spruce and balsam fir is attended with considerably more danger of windthrow of the remaining spruce than would be the case if hardwoods were mixed with the conifers.

Pure Stands of Balsam Fir

The most susceptible of all stands to budworm attack are the pure balsam-fir forests. Fortunately, the pure fir type does not often cover very large areas and is, therefore, not as difficult to handle as it otherwise might be. It is also fortunate that young vigorous stands of pure balsam fir, although they may be attacked

by the budworm, are usually not severely damaged. Not until the trees approach merchantable size are they likely to succumb to an outbreak.

In the few instances where pure, even-aged balsam-fir forests cover extensive areas they should be treated on the small-unit plan so that by logging and cultural operations such forests will be broken up into uneven-aged units.

Reduction of Budworm Hazard by Logging Operations

It seems clear that the greatest possible degree of safety from budworm outbreaks can be attained only when and where cultural operations prior to logging are practicable. Nevertheless, the possibility of attaining at least partial control through logging should not be overlooked. In logging, the balsam fir that is cut should always include the smallest possible merchantable size and, when present, should be used in preference to other more valuable species in road construction, for stakes, and for other purposes where small trees are needed in connection with the logging operations.

Wherever practicable, logging should be conducted according to the small-scattered-unit plan so that succeeding stands will be composed of trees of diverse ages. The most susceptible stands should be cut first in so far as this is compatible with the small-unit plan.

CONCLUSIONS

The silvicultural problems involved in handling the various types that are either susceptible or potentially susceptible to budworm outbreaks are by no means simple. They are concerned not only with the present but also with future tree generations. As previously stated, the foregoing suggestions cover only the more common situations that arise and therefore cannot fit all cases. The particular procedure adapted to conditions existing at a particular time and place usually can be determined best on the ground. Too specific instructions made at a distance are dangerous if followed too literally. Much must be left to the judgment of the silviculturist directly in charge of the field work. For that reason it is particularly important that men directing cultural operations should know not only silviculture but also the effect of cultural procedures on insect populations. In decid-

ing upon cultural procedures for northern coniferous forests the following points should be kept continually in mind:

1. The natural course of forest succession in much of northeastern Minnesota leads toward a climax type containing a very high proportion of balsam fir.

2. Balsam fir overtopped by aspen, birch, or white pine is not conducive to budworm outbreaks. It is only after the tops of the fir trees project into or above the upper crown canopy that conditions are particularly favorable for this insect. The last outbreak caused very severe damage only in mature stands where balsam fir comprised more than 40 per cent of the upper crown canopy and where such stands occurred over extensive areas.

3. Balsam fir should be grown in as short a rotation period as possible, preferably not over 60 or 65 years. Short cutting cycles within the rotation period will reduce the period of susceptibility to the budworm and also help to avoid much of the loss caused by heart rot, which is prevalent in overmature trees.

4. The danger of budworm outbreaks may be reduced to a minimum by practices that will prevent the development of susceptible types. If this is impossible or undesirable, an attempt should be made to keep the relative proportion of budworm-susceptible types low at all times, to limit the size of individual tracts of susceptible types to the minimum size that can be economically handled as a unit, and either by cultural operation or by logging, to separate them from one another by nonsusceptible types or by stands that will not become susceptible until a later date.

5. Sporadic outbreaks may occur on small, favorable areas, but disastrous outbreaks have been invariably associated with extensive areas of susceptible forest types.

6. It is believed that the procedures suggested above will prevent extensive budworm outbreaks and thus result in a better chance for salvage of any timber that may be killed by local outbreaks. This is highly important because balsam fir deteriorates very rapidly after the trees are killed.

Many of the cultural suggestions for management of coniferous forests in northeastern Minnesota may be impractical at the present time. It is hoped, however, that these suggestions will be given careful consideration and that those which can be fitted to

particular situations will be applied as far as possible. Balsam fir and its chief insect enemy, the spruce budworm, will undoubtedly play a very important part in the future production of timber in Minnesota as well as in certain other parts of the country. The tendency to place forests under more intensive management will very likely continue, and measures which seem impracticable at the present time may be readily accepted in the future. It, therefore, seems imperative that we use what information we now have in order to build up a background of experience on which to base more detailed recommendations.