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A Study of Insects Attacking *Pinus flexilis* James Cones in Cache National Forest

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A STUDY OF INSECTS ATTACKING *PINUS FLEXILIS* JAMES CONES IN CACHE NATIONAL FOREST

By

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of the requirements for the degree

of

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ABSTRACT

A Study of Insects Attacking Pinus Flexilis James

Cones in Cache National Forest

by

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Utah State University, 1970

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Department: Zoology

Six species of insects were found attacking limber pine cones from July 26, 1968, through October 4, 1969, in Cache National Forest. The three species considered of major importance are: Conophthorus flexilis Hopkins, Dioryctria abietella (D. & S.), and D. sp. near or disclusa Heinrich. The three minor species encountered are; Bradysia sp., Trogoderma parabile Beal, and Asynapta keeni (Foote). In addition to the major and minor cone pests three parasites, Apanteles sp. prob. starki Mason, Elacherus sp., and Hypopteromalus percussor Girault were found associated with the cone pests.

C. flexilis, which completely destroys the cone, was ranked as the number one pest on the basis of numbers present plus severity of damage. During 1968 and 1969 C. flexilis destroyed 11.47 percent of the 1500 cones examined, with a mean of 5.87 larvae per infested cone. The cone moths, D. abietella and D. sp. near or disclusa, were ranked second and third in importance respectively. D. sp. near or disclusa was potentially the more important cone moth, as it caused a total destruction of the seed bearing portion of the cones. However, D. abietella infested 15.40 percent of the cones, in contrast to 2.00 percent by D. sp. near or disclusa.

There were no significant statistical differences in insect populations between 1968 and 1969, although the percent infestation of *C. flexilis* and *D.* sp. near or *disclusa* increased slightly and *D. abietella* decreased.

(49 pages)

INTRODUCTION

Limber pine, Pinus flexilis James, is a high elevation tree of dry, rocky soil and is very intolerant of competition. It ranges through the Rocky Mountains from southern Alberta and British Columbia to northern New Mexico, extending westward through the mountain ranges of the Great Basin to southern California, northwestern Nevada, and eastern Oregon (Critchfield and Little, 1966). At the southern edge of its range it overlaps, and to some extent intergrades, with P. strobiformis. Steinhoff (1964) discussed the southern limits of limber pine. Throughout the range, limber pine rarely comprises a pure stand, but rather open scattered stands with mixed pine and fir associates.

It is important for us to understand some of the problems faced in the process of reforestation. Limber pine is not of great commercial value, although it has been used for various purposes such as mine timbers, watershed control and especially for its asthetic values. As with many tree species, limber pine has failed to restock satisfactorily on cutover land and pyric destroyed areas. Although it is possible to grow limber pine from rooted cuttings, the only practical way to produce a new stand is from seed.

In areas where limber pine thrives, high rocky slopes present a particularly serious problem. These areas are quickly invaded by various types of vegetation that form a rather stable community after the area has been disrupted by logging operations or fire. The reestablishment of limber pine in these areas is difficult due to its extreme intolerance of competition. Thus, time is an important factor in successful regeneration. If limber pine is not reestablished within a few years, then the only economical and practical way to attempt reforestation is to clear off the invading vegatation to reduce the competition for moisture, nutrients and light.

Problems of seed production and reforestation are of increasing importance. Knowledge of cone- and seed-destroying insects is in great demand in order that steps may be taken for their control. Keen (1952) stated that protecting forests from destruction is the first basic requirement in forestry. Insects which kill the trees often receive more attention, but forest insects other than tree-killing species present many special problems. They may be encountered in every operation from the collection of seeds to the planting, growing and harvesting of forest trees.

Insects that destroy the seeds of forest trees have a direct bearing on reforestation. This fact led to the present study of insects attacking the cones of limber pine. Not only is seed loss a limiting factor in natural stands, but it may be even more of a problem in tree nurseries. A high incidence of insect attack can make seed collections impractical or can result in poor germination once the seed is planted.

The destruction of limber pine cones by insects has been recorded as reducing the supply of seed (Keen, 1958). Research on the cone- and seed-destroying insects of limber pine has the potential of helping alleviate regeneration problems. Thus, the objectives of this study are to determine what limber pine cone and seed insects are present in a given area of northern Utah, to assess their relative abundance and damage, and to identify any predators or parasites of the cone and seed pests.

REVIEW OF LITERATURE

Keen (1958) stated that the importance of developing knowledge of cone and seed infesting insects was first recognized by John M. Miller in May 1912 when he proposed to Dr. A. D. Hopkins, then Chief of the Division of Forest Insect Investigations, Bureau of Entomology, United States Department of Agriculture, that a study should be made of cone and seed insects. Miller pointed out the need to assist the Forest Service in seed-collecting work, so collectors could avoid badly infested, unprofitable areas. This study was approved by Hopkins in June 1912, and during the remainder of 1912 Miller collected a good many seed and cone insects.

Keen went on to state that at first the work was centered at Placerville, California. In August 1913, Miller moved his headquarters to Ashland, Oregon, where cone and seed insect studies were the principle work of this sub-laboratory. P. D. Sargent collected many of the cones and seeds. In August 1914, the personnel at the Ashland station was augmented by J. E. Patterson, as an entomological ranger.

During 1914 and 1915 R. L. Furniss, J. H. Pollock, G. Hafer, B. T. Harvey and W. D. Edmonston made collections of limber pine cones and returned them to J. M. Miller, J. E. Patterson and F. P. Keen for examination and rearing. The work was continued through 1915 and 1916 until interrupted by World War I, during July 1917. Since then, cone and seed insects have been collected only occassionally, usually in connection with other lines of work.

From 1913 to 1950 most of the insect specimens collected were studied only taxonomically. Hopkins (1915) obtained type specimens and data for western species of Conophthorus from these collections. Heinrich (1926) described several species of moths. They were mentioned briefly as cone insects in "Insects of Western North America" by Essig (1926).

Since 1950 many investigators again have become interested in cone and seed insects. Lyons (1956) dealt with the brood aspect of insects affecting seed production in red pine. Herbert Ruckes, Jr. was one of the first to begin intensive study of the habits, life cycle, and taxonomy of cone and seed insects. Ruckes studied Conophthorus beetles in California from 1955 to 1957. During the past decade W. D. Bedard, D. L. Williamson, J. A. Schenk, W. F. Barr, and W. R. Henson have contributed a great deal to our knowledge of the biology and behavior of the cone beetles.

L. A. Lyons, M. R. MacKay, D. N. Radcliff, J. A. Powell and others studied the habits and damage of the fir cone worm.

There have been many other contributors including: F. P. Keen, T. W. Koerber, R. E. Stevens, R. W. Stark, and E. P. Merkel who have added to the information on a wide array of topics relating to cone and seed insects.

E. P. Merkel initiated the "Cone and Seed Insect Newsletter", in 1969. The following individuals are the major workers currently contributing to the studies of cone and seed infesting insects, in North America: J. W. Dale, University of Idaho; E. P. Merkel, A. Barcia, B. Ebel, D. Kucera, B. Mattson, S. W. Meso, D. Parker, W. B. White, and V. F. McCowan all of the United States Forest Service; K. J. Stoszek, Weyerhaeuser Co.; W. W. Neel, Mississippi State University and A. F. Hedlin, Canadian Forest Service.

A review of the available literature made it evident that the life history and basic life cycles of most of the insects associated with limber pine are known. The seasonal history of *Conophthorus flexilis* Hopkins is not well understood and is the major exception.

COLLECTING AREA

Logan Canyon, Cache National Forest, was selected for the primary area of this investigation. One site near the head of St. Charles Creek in Idaho, also in Cache National Forest, was included in the study. Logan Canyon was selected because it is one of the larger and more important canyons of northern Utah and is accessible for study most of the year. In this area, five collecting sites were chosen. In choosing the site such factors as slope, aspect, elevation and the age of the stand were considered. As many variables as possible were considered before the site was selected.

Site No. 1 was located at an elevation of 7750 feet, near the summit of Logan Canyon. It was an open, even aged stand of mature and overmature trees, on a slope of less than 10 percent. The aspect was northeast. Collecting site No. 2 was at an elevation of 7550 feet, with a southwest aspect. It was a stand of pole size and mature trees. The slope was less than 10 percent. Site No. 3 was an open stand of young mature, even sized trees on a slope of approximately 15 percent. It had a southwesterly aspect at an elevation of 7400 feet. Collecting site No. 4 was located near the head of St. Charles Creek drainage in Idaho, some 12 miles north of Beaver Mountain ski area and 8 miles west of St. Charles, Idaho. It was a stand of mature and overmature trees at an elevation of 7300 feet. The slope was less than 10 percent. The fifth collecting site was located approximately one-quarter mile southwest of the Beaver Mountain ski area, at an elevation of 7000 feet. It was a stand of young mature trees on a slope greater than 50 percent.

METHODS

Sampling began July 26, 1968, and continued through October 1969. At the start of the study, the first year cones were about 3.5 cm long and the second year cones were approximately 6.5 cm long. Second year cones were particularly abundant. The cones of the first growing season were not abundant.

Collecting the cones was accomplished by using various pole pruners. At first an 8-foot wooden pruner was used, but this limited the collections to the lower crown. The maximum height, with this pruner, was 18 feet. Hence a second pruner was used, a sectional aluminum pruner extendible to 30 feet. This allowed me to reach some 37 feet into the crown. In order to take samples from the upper crown, I had to climb trees and then use the 8-foot wooden pruner to reach the cones near the ends of the branches. This presented some bias in selecting climbable and unclimbable trees. However, the majority of sampling was from the mid- and lower-crown levels due to expediency.

The removal of the cones from the trees was accomplished in two ways. First the cones were pulled from the limb, by hand or pruner, to prevent further injury to the terminal portion of the limb. Secondly, when the cones could not be pulled from the limb, the terminal portion of the limb, bearing cones, was clipped. Due to the potential injury to the limb, from the cutting procedure, it was used only occassionally on trees where the cones were difficult to remove from the limb. This was to prevent any undue injury or suppression of growth.

When the cones were removed from the mid- and upper-crown levels, they fell to the ground and dislodged insects feeding on the exterior, so I attached a hoop, with a cloth bag on it near the cutting head of the extendable pruner. The cones fell into the bag and surface feeders were picked from the bag. This practice was discontinued during the later phases of the research because insects affecting seed production and destroying the cones fed in the cones rather than on the surface. A number of Hemiptera were collected in the bag, but they were never seen feeding on the cones.

Samples were taken from each of the sites at biweekly intervals. A sample consisted of collecting 50 cones from each site, with a total of 250 cones collected from the study areas.

The sampling procedure was not entirely randomized. A completely randomized sample was biased by accessibility. Some portions of the tree could be sampled, others could not. However, where possible, all quadrants and crown levels were sampled to eliminate as much of the bias factor as possible.

Of the 50 cones collected from each site, 25 were dissected and the remaining 25 were placed in rearing chambers. Where there was an abundance of cones, additional cones were brought in and placed in rearing chambers in order to increase the chances of obtaining adult specimens.

The dissection of the cones consisted of placing the cone on a board and cutting it longitudinally with a knife or a cone cutter. The resulting bisection (Figure 1) was examined for egg, larvae, pupae, and adults. Each half was then cut longitudinally again, thus exposing eight surfaces that were examined in detail. Sectioning of the cone in this manner facilitated the examination of the seeds. Every seed was not

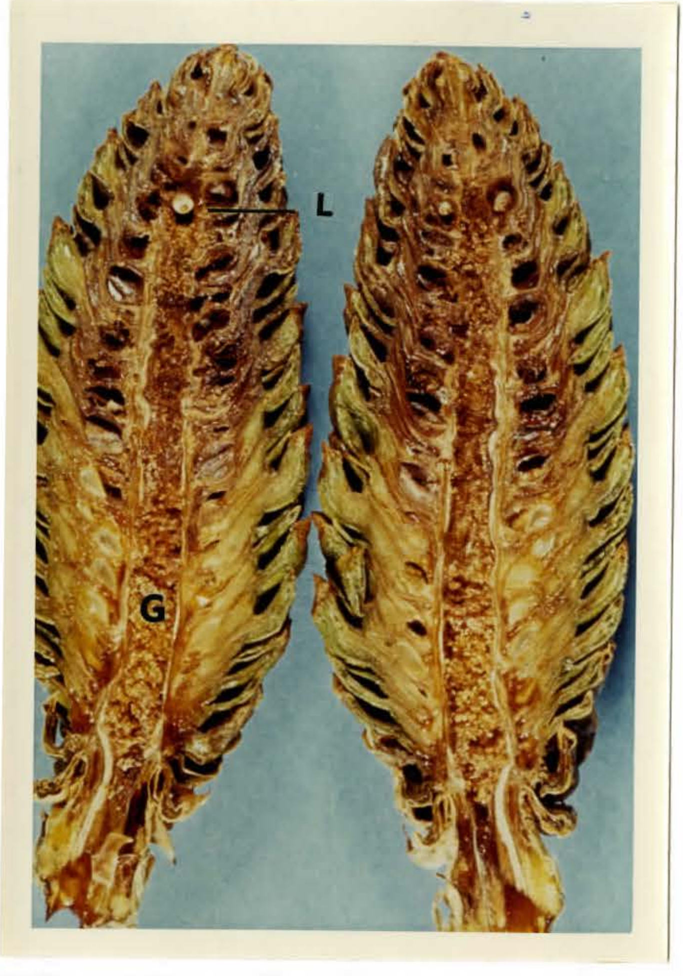

Figure 1. Longitudinal section of cone showing: L. larva; G, gallery, of C. flexilis.

examined, only those exposed by the sectioning. However, each bract was pealed back, and examined.

Separate records were kept of each species found infesting or causing damage to the cones or seeds. The larvae were counted and separated as closely as possible to species and sent to specialists for identification.

The rearing techniques were similar to those used by J. E. Dewey (1965). Cardboard dairy cartons of varying sizes were used as rearing chambers. A few, of the gallon containers were fitted with a test tube one inch in diameter and eight inches long extending out of the carton. This was ineffective in attracting the insects to light after emerging from infested cones and seeds. The pint and half-pint containers were fitted with a sheer cloth that would facilitate the observation of individual infested cones. The cloth was fitted into the lid of the container. This proved more effective in making counts of insect emergence from a cone.

The cones, in the gallon containers, were placed in a rearing room at 70^{o} to 80^{o}F. The photoperiod averaged 16 hours photophase and 8 hours scotophase. The photoperiod varied somewhat, but this had no apparent effect on the emergence of the insects.

The pint and half-pint containers were placed in a growth chamber at the United States Forest Service laboratory at Ogden, Utah. The humidity was maintained at 72 percent through a 12-hour scotophase and was lowered to 60 percent for the 12-hour photophase. The temperature through the 12-hour scotophase was 86^{o}F and 60^{o}F through the 12-hour photophase. This method proved very successful in acquiring adult specimens.

There were some difficulties with rearing the larvae in the gallon containers. The young succulent cones were covered with mold as a result of high temperatures and humidities. Cones placed in the growth chamber were devoid of such growth. Second year cones were mold-free, probably due to the nearness to maturity. The presence of the mold undoubtedly affected the development of the larvae and pupae of Dioryctria which normally leave the cones to pupate in the duff.

Only one insect species was found as a larvae then failed to mature. Identification of this species was based on larvae only.

September 1, 1969, twenty branch tips with developing first year cones, were covered with a cloth bag (Figure 2 & 3) in an attempt to capture any insects developing in the first year cones. There was a possibility that the fir cone worm might injure first year cones (Figure 4). The first year cones were apparently devoid of pests, except for possible periods of food shortage or over population of cone pests. One-hundred and fifty first year cones were dissected and found free of pests.

Figure 2. Terminal portion of limb bagged.

Figure 3. Bagged terminal showing first year cones.

Figure 4. First year cone being fed on by Dioryctria abietella larva, L.

RESULTS

Insects Associated with Limber Pine Cones

The following insects were found in or associated with *P. flexilis* cones:

Cone Feeders

- Coleoptera
  - Scolytidae
    - *Conophthorus flexilis* Hopkins
- Lepidoptera
  - Phycitidae
    - *Dioryctria abietella* (D. & S.)
    - *D.* sp. near or *disclusa* Heinrich
- Diptera
  - Sciaridae
    - *Bradysia* sp.

Parasites

- Hymenoptera
  - Braconidae
    - *Apanteles* sp. prob. *starki* Mason
  - Eulophidae
    - *Elacherus* sp.
  - Pteromalidae
    - *Hypopteromalus percussor* Girault

Miscellaneous Cone Associated Insects

- Coleoptera

Dermestidae

Trogoderma parabile Beal

Diptera

Cecidomyiidae

Asynapta keeni (Foote)

Of these species, three were significantly injurious. The three considered important are: *C. flexilis*, *D. abietella*, and *D.* sp. near or *disclusa*. The remaining were found in too small of numbers to be evaluated as significantly injurious. I was unable to determine if they were injurious to the cones and seeds or were simply accidental visitors.

Percent infested and severity of damage were the two main factors used in determining the importance of a cone pest. In this study, the three significantly injurious species occurred in all sample areas with the exception of *D.* sp. near or *disclusa* which was not found infesting cones on site No. 4. The two species which were of most general occurrence, *C. flexilis* and *D. abietella*, differed greatly in their severity of damage. *C. flexilis* completely destroyed the cones, but was unevenly distributed on a tree to tree basis. *D. abietella* was relatively evenly distributed and little difference was observed from site to site. However, the damage caused by *D. abietella* and *D.* sp. near or *disclusa* was less severe than that of *C. flexilis*. *C. flexilis* caused more total damage to the crop and individual cones than *D. abietella* or *D.* sp. near or *disclusa*.

Conophthorus flexilis Hopkins

Limber pine cones that dry and wither before they are half grown are often called "blighted cones". C. flexilis is the usual cause of this type of damage, which is characterized by the dying of the immature cones soon after starting their second year's growth. These blighted cones are usually smaller than a normal cone and appear faded (Figure 5).

C. flexilis was first described by Hopkins in 1915. Subsequent authors added little to this brief description until 1947 when Wood described C. flexilis as follows:

> Length 3 to 3.8 mm, 2.7 times as long as wide; color dark brown to dull black, sparsely covered with fine, long yellow hair; head usually completely withdrawn into the pronotum. Frons convex above, narrowly flattened above epistomal base, with a very feeble longitudinal carina on lower portion; punctures large, deep, moderately close; pubescence mostly limited to epistomal margin. Eyes oval, triangularly emarginate, one-third divided. Antennal funicle five segmented; club non-septate. Pronotum about as long as wide, widest basally, narrowed anteriorly and rather narrowly rounded in front; aspenties numerous, rather low, extending beyond middle at sides; punctures large, deep, rather close; pubescence of short sparse yellow hair. Elytra 1.4 times as long as wide, wider than pronotum; sides nearly straight and subparallel on anterior half, broadly rounded behind; striae feebly impressed, punctures small, deep, separated by their own diameters, in obscure rows, smaller and shallower laterally; interspaces shining, twice as wide as striae, punctures sparse, as large as and similar to those of striae; pubescence of very sparse, long yellow hair. Declivity very broadly, weakly sulcate, third interspace elevated and with a few small setose granules; sulcus faintly or not at all punctured, glabrous, shining, and obsolete before the apex.(Wood, 1947,p. 46)

The larval form (Figure 1) is typical of scolytid larva, comma shaped in general appearance. They are creamy white, with a brownish head capsule and pass through two larval instars.

Life history. The immature cones were killed during the second summer of growth by the adult female Conophthorus beetle burrowing into the

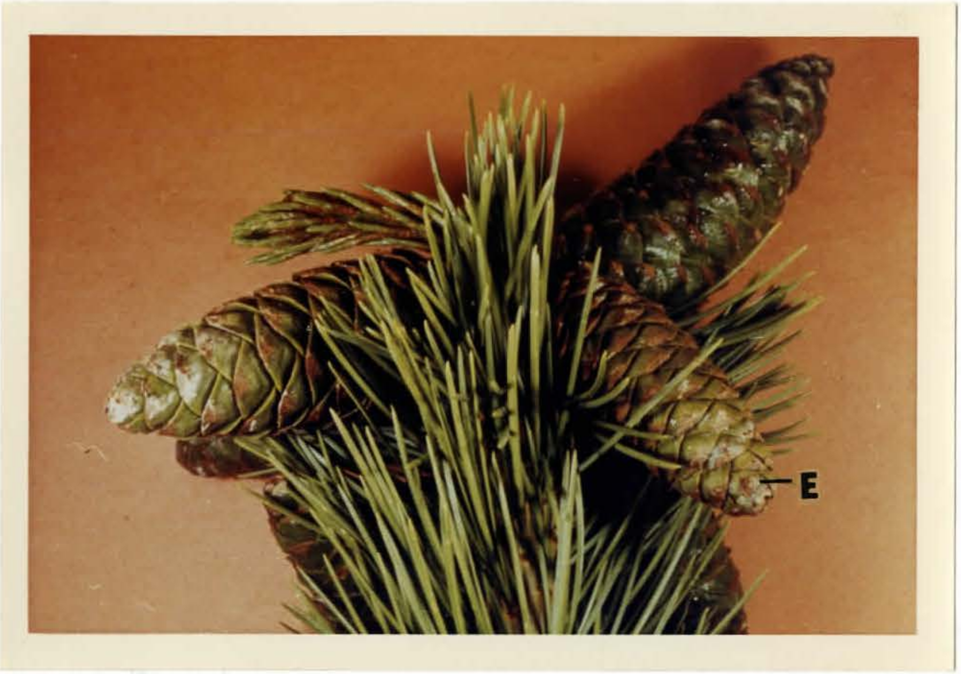

Figure 5. Center cone infested with <u>C. flexilis</u>. E, exit of parent adult.

cone to deposit eggs. Rarely is the male associated with the initial attack on the cone. The female beetle bores through the cone scales at the proximal end of the cone near the petiole, then continues through the basal scales to the woody conducting tissues surrounding the axis. The gallery was extended into the axis of the cone (Figure 1), thus killing it before maturity. In rare cases, the gallery was observed extending along the axis, rather than within the axis.

Cone attacks were generally solely by the females which have presumably mated. Those accompanied by a male, mate within the gallery. There was an area near the point of entrance where the male may remain for a short period of time and mate prior to gallery formation. This area may be referred to as the nuptial chamber or a mating niche.

Oviposition takes place simultaneously with gallery formation. The eggs were laid singly or in pairs in individual niches carved in the gallery wall or in seeds along the gallery. After the egg or eggs were laid, they were covered with frass and debris before extending the gallery. The egg niches appear to be evenly spaced and extend to the area approximately at the end of the axis. The number of eggs laid per cone was dependent on the length of the cone at the time of oviposition. C. flexilis packs the gallery with frass and debris while excavating the gallery from the proximal towards the distal end. Upon completion of the gallery, the female leaves the cone by burrowing through to the outside near the distal end of the cone (Figure 5). Before leaving the cone, she plugs the exit with resin and debris which later hardens and prevents invasion of foreign organisms.

Hatching occurred within a few days to a week following oviposition, producing limbless, white larvae with light-brown head capsules (Figure 1).

The larvae first consumed the seed or tissue near the point of egg deposition, then proceeded to feed indiscrimately within the cone. The larvae made irregular-shaped openings in the seed coat and produced irregular, granular, dark brown frass. They tunneled without any particular pattern. Larval development was completed in 2 to 3 weeks.

Pupae were present approximately a month after the first attacks in June (Figure 6). Pupation took place within the cone. A shallow pocket was excavated in the cone tissue, but usually, by this time the drying cone tissues had collapsed, and the pupal development occurred within this space. Pupal development was rapid, and transformation to adults occurred within a few weeks after pupation.

Most of the newly developed adults remained in the blighted cones until the following spring. By this time, the cones had normally dropped to the ground (Figure 7), and the new adults apparently continued to feed on the drying cone tissues through the winter. They regained activity after 8 to 14 hours in the laboratory. There is one generation per year (Keen, 1958).

The primary time of emergence for C. flexilis was in June and early July in the Cache National Forest. As with other members of the genus Conophthorus, temperature appears to be the main factor controlling emergence.

Overwintered young beetles were sexually mature when they emerged from their hibernation quarters. The emergence appeared to be synchronized with the beginning of the second year cone growth. They attacked the second year cones during June and July.

Damage. Heavy damage, up to 80 percent of the cones killed on 1 tree and 60 percent of the crop infested, has been reported in some years where as 5 percent has been reported in other years (Keen, 1958).

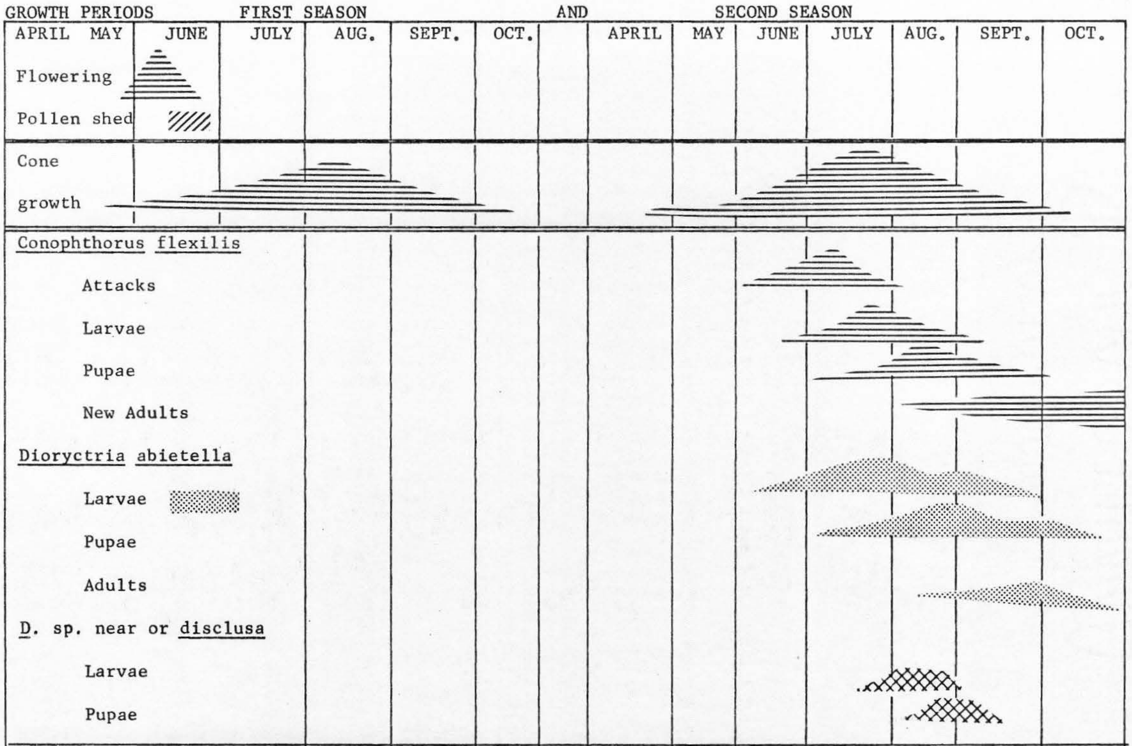

Figure 6. Time and duration of development of insects attacking limber pine cones in relation to flowering and cone growth, Cache National Forest, 1968 and 1969. Relative populations are estimates.

Figure 7. Overwintering area of C. flexilis in fallen cones and pupation site of D. abietella in the duff.

In this study, 172 of the 1500 (11.47 percent) cones dissected were infested with C. flexilis (Table 1). The highest percentage infestation occurred on site No. 4 where 28.67 percent of the cones dissected were infested. On a few individual trees, as high as 70 percent of the cones were infested. A great amount of variation occurred from tree to tree within any given site.

Cones were invariably killed within a few weeks following attacks by C. flexilis. With C. flexilis, seed loss could be determined directly from cone damage. Koerber (1967) stated for accurate information on the frequency and severity of damage it would probably be necessary to examine all the cones from a large number of trees and express the loss in terms of cones per acre or proportion of the total crop on a large area.

Dioryctria abietella (Dennis & Schiffermueller)

D. abietella infests the cones, shoots, and bark of many different conifers, and is apparently holoarctic in distribution (MacKay, 1943). The fir cone worm is capable of causing heavy seed losses. It was one of the major pests attacking limber pine cones in 1968 and again in 1969.

Keen (1958) described this insect as follows:

> Adults are bluish-gray moths, dusted with white, mottled with dark brown, with two narrow light-tan zigzag lines across the forewings alternating with dark brown wider bands. The hindwings are uniformly dusky white with a darker border near the margin. Alar expanse 20-30 mm, body 12 mm. Pupae are dark reddish brown, 11 mm long, terminal segments broadly rounded, bearing 6 thin spines; usually in silk-lined papery cocoons encrusted with dirt. Larvae are long, smooth, nearly naked caterpillars of variable coloring, 17-20 mm long, to 2.5 mm wide; upper half of body iridescent green and red to amber brown, with faint mid-dorsal and broader subdorsal stripes, venter flesh-colored; 18-20 long yellow bristles on each segment, more than 5 times as long as the diameter of the spiracles; head shiny brown with cervical shield paler; anal shield large and dull brown; 5 pairs of prolegs on 6^{th} to 9^{th} and 12^{th} segments; very active. Eggs are oval, 1 by 0.65 mm, pink, with red spots on surface.

Table 1. Percentage of damage to limber pine cones by insects and mean number of larvae per cone 1968 and 1969

Site Number	Number of cones examined	Percent of cones damaged	Percent of cones infested by: *C. flexilis*	*D. abietella*	*D.* sp. near or *disclusa*	$\bar{X}$ number of larvae/infested cone: *C. flexilis*	*D. abietella*	*D.* sp. near or *disclusa*
1	300	28.33	9.00	16.33	3.00	7.08	1.01	1.22
2	300	21.00	7.66	12.00	1.33	4.84	1.00	1.00
3	300	23.00	6.00	13.67	3.33	4.40	1.00	1.33
4	300	52.00	28.67	23.33	0	5.55	1.00	0
5	300	20.00	6.00	11.67	2.33	7.50	1.00	1.57
Total	1500	28.87	11.47	15.40	2.00	5.87	1.00	1.28

Life history. D. abietella has been reported as overwintering in several different stages: partly grown larvae (Craighead, 1950), prepupae (MacKay, 1943), and pupae (Brown, 1941). D. abietella adults were common in August, September, and October in the Cache National Forest. Larvae were found during June, July, and August.

Lyons (1957) reported that there is an overlap in generations in D. abietella attacking red pine cones. This overlap in generations was also detectable in D. abietella in limber pine cones. The seasonal history of D. abietella in limber pine cones appeared to be the same as that recorded in red pine and ponderosa pine cones. Koerber (1967) stated the larvae bore circular gallaries, usually lined with thin silk webbing, through the cone scales. Most of the frass is removed from the gallery and webbed together in an irregular mass on the surface of the cone, covering the gallery entrance. By the time most of the larvae reached the seed-bearing portion of the cones, the seed coats were hard enough to resist their feeding efforts. Thus, the seed was not destroyed directly, but some of the sound seed was trapped in the cones by masses of frass and webbing. Damaged cone scales often failed to open properly. The seeds were sometimes fed upon and destroyed by early larval attacks.

The larvae pass through five instars (Lyons, 1957). Larvae maturing in July and August become adults in late summer. These new adults mated and produced progeny which appeared to overwinter as young larvae. Some larvae pupated and spent the winter in thin, debri- and frass-coated cocoons on the exterior of the cones or even in the duff at the base of the tree (Figure 7). These emerged the following spring as adults. Laboratory reared larvae usually left the cone to pupate.

Oviposition sites were not investigated in this study. Lyons (1957) reported that the eggs were invariably deposited singly in the shallow crevices between adjacent cone scales on second-year cones under laboratory conditions. No eggs were found in the field studies.

Damage. Limber pine cones were damaged in June, July, and August, with the highest damage occurring in late July. In this study, 231 of the 1500 (15.4 percent) cones dissected were infested with D. abietella. The highest infestation occurred on site No. 4 where 23.33 percent of the cones dissected were infested. Percentage comparisons of 1968 and 1969 are shown on (Table 2).

The larvae fed primarily on the cone scales of the second-year cones. However, a number of larvae were observed feeding on the exterior of the first-year cones (Figure 4). Young larvae tended to enter the cone near the petiole and tunnel through young seeds near the axis. Mature larvae tended to remain near the surface and feed on the distal portion of the cone scales. The mature larvae kept their tunnels free of debri, and moved about freely. When alarmed, they withdrew rapidly. The mature larvae also migrated freely from one cone to another in the same whirl. As many as 4 D. abietella larvae were observed feeding on a single cone. However, of the 1500 cones examined there was a mean of one larva found per damaged cone (Table 1).

Dioryctria sp. near or disclusa Heinrich

D. sp. near or disclusa was identified from larval specimens only. I was unable to rear any adult specimens for identification. Until recently this species has been referred to as D. auranticella Grote. However, according to Heinrich (1926), D. auranticella is a western species

Table 2. Percentage comparisons of cones attacked by major insect species

Site	July 9, '68 Through Oct. 4, '68			July 9, '69 Through Oct. 4, '69		
	C. flexilis	*D. abietella*	*D.* sp. near or *disclusa*	*C. flexilis*	*D. abietella*	*D.* sp. near or *disclusa*
1	10.67	27.33	2.00	9.09	7.27	10.91
2	4.67	17.33	0	10.91	10.91	7.27
3	4.67	19.33	2.00	10.91	14.55	12.73
4	34.67	40.00	0	38.18	12.73	0
5	6.67	18.67	1.33	12.73	5.45	9.09
Total	12.27	24.53	1.07	16.36	10.18	8.00

and synonymous with D. xanthoenobares Dyar and is not the species encountered in these studies. D. disclusa is supposedly confined to eastern North America, where it is found as far west as Iowa and southward to North Carolina (Lyons, 1957). Heinrich was unable to distinguish the larvae from D. disclusa and his monograph does not contain diagnostic features for the larval stages (Farrier and Tauber, 1953).

The description of D. disclusa larvae by Lyons (1957) is as follows:

> The mature larva of D. disclusa is a slender, olive-green to buff caterpillar, 14 to 18 mm long, with lighter patches dorsally and laterally on each segment. There are five instars, the mean head widths of which are: instar I, 0.26 mm; instar II, 0.40 mm; instar III, 0.57 mm; instar IV, 0.92 mm; and instar V, 1.44 mm. The approximate length of preserved larvae is: instar I, 2-3 mm; instar II, 3.5-4.5 mm; instar III, 4-7 mm; instar IV, 8-12 mm; instar V, 13-18 mm. Head varying from pale yellow-brown to dark orange- or chestnut-brown; genal markings varying from pale indistinct to dark brown distinct; mandibles reddish in newly eclosed larvae, later blending in color with rest of head. Pronotum grey-brown to orange-brown, mottled with black in mature larvae; legs pale in young larvae, later darkening; seta rho of mesothorax conspicuously longer than others, inserted in a ringed sclerite rather than a solid one: Kappa setal group of prothorax occasionally trisetose rather than bisetose. Abdominal segmentation distinct; setal sclerites in instars I to IV usually concolorous with rest of body surface, those of instar V dirty white to brilliant white; seta rho of eighth segment conspicuously longer than others, inserted in a ringed sclerite; proleg crotchets of instars I and II uniserial and uniordinal, those of instars III to V uniserial and biordinal; epiproct light brown.

A few larvae pupated but adults failed to develop. The pupae matched the description of D. disclusa in that they were long, robust, heavily sclerotized, with thick, lyre-shaped caudal hooks. In comparison, D. abietella pupae are more slender and delicate than D. disclusa, with straight, slender caudal hooks.

Life history and damage. D. sp. near or disclusa occurred so infrequently in this study that it was not possible to gather extensive information on its life history and damage.

According to Lyons (1957), D. *disclusa* spends the winter as first-instar larvae in thin, flat hibernaculam beneath the bark scales. The exact time of emergence from hibernation is not known. Upon emergence, the larvae fed on the staminate flowers and remained there until about the time of pollen shedding, when the older larvae migrated to, and attacked second-year cones. In Cache National Forest, D. sp. near or *disclusa* was found attacking second-year cones in July and August when the cones had attained about half their final growth.

On attacking the cone, the larvae of D. sp. near or *disclusa* bored a round, clean-cut entrance hole, in the proximal end of the cone near the petiole. The larvae slowly excavated large feeding chambers in the seed-bearing region of the cone. The resulting cavity may become partially filled with resin and frass. In a few cones this resin and frass mixture began to decay and caused extensive damage to the surrounding tissues. However, this decaying material had no apparent direct effects on the larva. Several of the cones died from the excavation of the large feeding gallery by severing the conducting tissues in the axis.

The few pupae which were observed pupated within the cone. A larva would spin a thin cocoon inside the cone, near the entrance tunnel. This habit is characteristic of both D. *disclusa* (Lyons, 1957) and D. *auranticella* (Koerber, 1967).

The damage caused by D. sp. near or *disclusa* can be distinguished from C. *flexilis* and D. *abietella* by the large, clean cut entrance hole near the petiole. The entrance hole is free of frass, debri and the resin plug as in the case of C. *flexilis*.

In this study, 30 of the 1500(2.00 percent) cones dissected were infested with D. sp. near or disclusa (Table 1), D. sp. near or disclusa was found in each of the sites except No. 4.

Other Insects

In addition to the major cone and seed pests of limber pine, six additional insect species were collected. Three appeared to be minor or secondary cone and seed pests, while the other three were parasites. These six species occurred in small numbers and apparently caused neither serious damage nor a high degree of control.

The three minor pests are; Trogoderma parabile Beal, Bradysia sp., and Asynapta keeni (Foote). They were found in limber pine cones so infrequently, that their damage and percent infestation was not determined.

T. parabile has created some interest in other work with cone insects, but only 27 specimens were reared in these studies and its role could not be determined. R. S. Beal, Jr. stated, in personal correspondence of October 14, 1969, that it is conceivable that T. parabile might feed on seeds in the cones, if the seeds were still in the cones and if the cones were kept in protected and moderately dry storage. This species has been found, as a pest, in many stored products of high protein content.

Fifteen Bradysia sp. were reared from the seeds of limber pine cones in these studies. It has been found in association with other coniferous seeds. Information was not obtained on the larval habits, but most members of this group are fungus feeders.

The cone resin midge, A. keeni, is common in the cones of many species of western coniferous trees, where it feeds on small patches of resin between the cone scales. A. keeni was found infesting only seven limber pine cones and caused little apparent damage. They may induce resin formation upon which they feed, possibly causing the cones to abort. Where they are abundant, they inflict some damage by preventing the seeds from falling to the ground (Keen, 1958).

The three parasites are: Apanteles sp. prob. starki Mason, Elachertus sp., and Hypopteromalus percussor Girault. They were identified from adult specimens collected in the rearing chambers. They also occurred so infrequently that their biology could only be surmised. There is some literature available relating to their importance as parasites (Keen, 1958).

DISCUSSION

In this study three insect species were considered to be important pests of Pinus flexilis cones. They were Conophthorus flexilis Hopkins, Dioryctria abietella (D. & S.) and Dioryctria sp. near or disclusa Heinrich. The importance of each major species was based on frequency of occurrence and amount of seed damage caused to an infested cone by the insect species.

The damage caused by each of the major species was easily separated and estimates were made on the amount of damage caused by each species. The expected number of seeds per cone, as indicated by seed counts in cones from both the 1968 and 1969 crops, was 75.72 ± 10.39 with correlation to a 99 percent confidence interval of probability. Approximately 25 percent of the seeds were small of which many failed to develop into normal seeds. Nineteen percent of the small seeds were normal. Thirteen percent of the large normal appearing seeds failed to develop normally and were unfilled or had aborted.

Extreme variation in the number of cones available for attack tend to obscure the relationship between insect populations and total damage (Koerber, 1967). In 1968, there was an abundance of second year cones available for attack and the percentage infestation was lower than in 1969 when there were fewer second year cones available for attack. The relative intensity of damage varied inversely with fluctuation in cone production. That is, the intensity of damage increased following a decrease in cone production, and the reverse was true. The decrease in cone abundance could result in competition between different insects.

However, this was not observed in this study.

C. flexilis was the most destructive of the major cone and seed pests of limber pine. Each female apparently had the potential of killing more than one cone per year. Depending on climatic conditions, she could destroy an estimated 150 to 225 seeds per year. In this study, 11.47 percent of the cones examined were infested. Although the total cones attacked is relatively small, the damage is great due to the fact that all seeds in an infested cone are destroyed. Approximately 13,072 seeds were destroyed by this species in the examined cones. C. flexilis was found infesting cones on each of the study sites during both 1968 and 1969 indicating it is a potentially serious threat to the cone crop. The percentage of cones attacked by C. flexilis increased from 12.27 percent in 1968 to 16.36 percent in 1969 (Table 2). The cone beetle also appears to be more competitive for cones than the other cone pests, due to its earlier attack, and mode of entrance which ensures the death of the cone through cutting the conductive tissues. This produces an ideal environment for larval and pupal development, and prevents attacks by other cone insects. C. flexilis was never found infesting cones with any one of the other species.

D. abietella has been found in a number of different species of conifer cones in Cache National Forest. It was found rather evenly distributed throughout this study area. Based on other studies, Dewey (1965), Lyons (1957), Koerber (1967), not including limber pine, it does not appear to be the host preference. Douglas-fir is apparently preferred.

The amount of damage caused by D. abietella was approximately the same in all sites. The fir cone worm damage was less severe than that of the cone beetle, C. flexilis, in that it did not kill the cone and was generally found mining in the peripheral portions of the cone. Comparatively few seeds in the infested cones was destroyed from late season attacks. Seed was sometimes trapped in the cones by masses of frass and debri. The small cones, which had been attacked early in the season, suffered some seed loss through direct feeding by the larvae. The majority of the seed loss caused by this species was through the failure of cones to open properly at maturity and shed the seed.

In this study D. abietella occurred on all study sites, where a total of 15.40 percent of the cones examined were infested (Table 1). Very seldom was more than one larva found feeding on a cone. The majority of the cones infested were encountered during mid-summer, when the cones were nearing maturity and damage was, therefore, slight. The number of seeds destroyed directly ranged from 0.3 to 5.2 seeds per cone. The number remaining in the cones at maturity, due to improper opening, was not determined.

Comparing 1968 and 1969 the population of D. abietella dropped from 24.5 percent in 1968 to 10.18 percent in 1969 (Table 2). This drop may have been due to the shortage of limber pine cones and the abundance of preferred host material. However, this difference was not statistically significant at the 10 percent level, when comparing percent infestation.

Owing to the relative scarcity of D. sp. near or disclusa in the study area, it was not possible to gather extensive information regarding the habits and damage of this cone insect. Lyons (1957) stated that cones unsuccessfully attacked may survive and produce seeds, but most cone attacks are fatal. The latter appears to be the case with the attacks on limber pine cones. Each larva apparently attacks two cones. In some cases 3 larvae were found attacking the same cone.

Damage caused by D. sp. near or disclusa is much more severe than that caused by the fir cone worm. In some respects, it was almost as severe as damage by C. flexilis. The major portion of the damage occurred during the excavation of large feeding galleries within the seed bearing area of the cone. The percentage of seeds destroyed directly, ranged from 20 to 100 percent per cone. The seeds not destroyed directly were apparently lost due to death of the cone prior to maturity or due to the fact that the cone failed to open. Although the population apparently increased during 1969, the difference was not statistically significant (Table 2).

Of the three minor species (Trogoderma parabile Beal, Bradysia sp., and Asynopta keeni (Foote)) T. parabile appears to be important only in storage areas. This species was not encountered in the field, even from the examination of cones in squirrel caches. It might become a serious pest of untreated seeds in nurseries. Owing to the scarcity of this pest, little information was obtained regarding its actual importance to seed production. Further research could reveal that it is an important species.

There was little information obtained concerning the habits of Bradysia sp. attacking limber pine cones and seeds. Keen (1958) reported that B. coprophila (Lint.) were reared from acorns of white oak and seeds of Oregon ash, and B. pauciseta (Felt) adults were reared from Douglas-fir cones. Hence, it appears that other members of this genus have been found infesting seed. This is in contrast to the fungus feeding habits of the majority of the members of the family Sciaridae.

The tiny black midge encountered in this study was found most commonly in association with one of the other major cone pests. It could very easily have been feeding on the fungi present.

The cone resin midge, A. keeni, is common in the cones of many species of western coniferous trees, where it feeds on small patches of resin between the cone scales (Keen, 1958). Contrary to the general abundance of this species in the cones of some conifers, it was found in small numbers infrequently attacking limber pine cones. Keen (1958) stated that in September when mature cones are placed on sheets to dry, the midge larvae fall from the cones by the millions. The apparent large numbers that infest some coniferous cones was never observed in this study. Ten larvae, which later developed into adults, was the greatest number observed on a single cone. Throughout the entire study, only seven cones were found infested with A. keeni larvae. The only apparent damage, the formation of a small amount of resin, prevented some of the scales from separating at maturity and the seed from being shed.

The populations of the major insect species attacking limber pine cones, with few exceptions, was dependent on the supply of cones produced each year. This was particularly true of the cone beetle, C. flexilis which apparently infested only the cones of limber pine. The other cone pests in this study have more than one host. C. flexilis had no major parasites to serve as a means of population control. The cyclic cone supply, as found in limber pine, was so pronounced that it tended to preclude parasites becoming a dominant regulatory factor. In a year of cone shortage, interspecific competition may also play an important role in population density control.

D. abietella, *D.* sp. near or *disclusa* and the minor species, in the Cache National Forest, have the potential of developing very high populations due to their wide host range and the apparent absence of major predators or parasites. Dewey (1965) stated that under the present conditions, the amount of damage caused by the cone and seed insects probably does not justify any type of organized control measures. As greater economic interest develops in this area, and as logging, recreation, and public demands increase, reforestation will become more important. Hence suitable control measures, of which there are none at present, must be devised to control the cone and seed insects of all conifers if we are to maintain and continue our natural reforestation practices.

SUMMARY

The primary intent of this study was to determine what insect species attack the cones of limber pine and in what numbers they occur. The severity of damage was used to evaluate the importance of each major species. Parasites encountered were collected and identified.

During the course of this study, 3225 cones were collected and taken to the laboratory for dissection and rearing. Fifteen hundred cones were dissected and the remaining placed in rearing chambers in an attempt to obtain adult specimens for identification.

Nine insect species were encountered in this study. Only three of the insect species occurred frequently enough to be considered of any economic importance. These three important species are: Conophthorus flexilis Hopkins, Dioryctria abietella (D. & S.), and D. sp. near or disclusa Heinrich. The other six species occurred so infrequently that they were considered of minor importance. Three of these were apparently parasites of the cone-infesting insects.

C. flexilis infested 11.47 percent of the examined cones with a mean of 5.87 larvae per infested cone. This species also caused the greatest amount of damage, although infested cones occurred less frequently than with D. abietella. C. flexilis was ranked number one in damage severity and numbers involved. It has the potential of destroying thousands of seeds per year. The adult female were apparently able to attack more than a single cone and have progeny develop in each. The potential populations of C. flexilis are great,

but the intermittent cone crop tends to limit the numbers of insects. Under ideal environmental conditions, this species could build up a population during a peak cone production year so that the following year, assuming reduction in cone crop, there would be an almost total loss of cones.

C. flexilis has a twofold impact on limber pine cones. First, it is injurious by the mere presence of the adult female excavating the gallery, which invariabily destroys the cone before it matures, even if the progeny fail to develop. Secondly, the larvae feed on the seeds and cone scales, preventing the cone from opening and disseminating the remaining sound seed.

D. abietella infested a greater percentage of the cones, but was second in total number of individuals and damage severity. It was ranked second in importance, based on number of cones injured. *D.* sp. near or *disclusa* appeared to be inherently more destructive, but did not occur in such large numbers or as frequently as *D. abietella*. The fir cone worm, *D. abietella*, was injurious only in the larval stage and fed mainly on the distal portion of the cone scales. The main damaged occurred in late June, July and the early part of August. During the latter portion of the summer, the attacks were less severe. Some seed was fed upon directly by the tunneling larvae, but this occurred more frequently in the smaller cones. As the cones neared maturity, the larvae fed mainly on the cone scales. The resulting damage, particularly relating to seed loss, was the failure of the infested cones to open properly.

The third major species, *D.* sp. near or *disclusa*, was encountered very infrequently. It was ranked third on the basis of total damage inflicted on the second year cones. It completely destroyed the seed bearing region of the infested cones. The death of the cone was almost assured by the excavation of the large gallery that gave some of the infested cones a flaccid appearance. If it were to occur in greater numbers, it would easily pass D. abietella in total damage.

The population levels of these insects appeared quite constant during the two summers of this study. Although the populations of C. flexilis and D. sp. near or disclusa appeared to increase from 1968 to 1969, it was not statistically significant. This observation may have been biased by the fact that fewer cones were available for attack and a higher percent of the 1969 crop was subsequently infested. The population of D. abietella decreased during 1969. The other pest populations appear to be constant and not a great deal of change was observed between 1968 and 1969. Although population levels are regulated by a complex set of factors, the main factor was apparently cone supply.

The seed crop of limber pine fluctuates greatly. In years of bumper crops there is probably more than enough seed produced. However, with the apparent constant insect populations, seed production would be reduced considerably in years of light cone crops. The cones, in addition to insect attack, are subject to feeding by birds and rodents. They consume vast quantities of limber pine seeds, resulting in further seed losses. Another problem is encountered with the low germination of the remaining seed. It has been reported that only 20 to 40 percent of seeds of limber pine germinate. Without some control measures, limber pine, as well as many other coniferous trees, face serious regeneration problems.

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