ISSN 0734-9556

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August 1983

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ACKNOWLEDGEMENTS

The authors wish to thank Drs. W. F. Barr, R. W. Carlson, E. E. Grissel, M. W. MacGown, P M. Marsh, A. Mutuura, and C. W. Sabrosky for their assistance in verification and identification of specimens; Drs. A. R. Alford and J. B. Dimond for their many helpful suggestions on an early draft of the manuscript; and the McIntire-Stennis appropriations for funds to carry out this study.

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INTRODUCTION

Rose and Lindquist (10) reported a new species of Dioryctria (Lepidoptera: Pyralidae) feeding on red pine, Pinus resinosa Ait. in Ontario, Canada and the northern United States. They stated that it was not abundant in Ontario but caused extensive shoot damage in the northern United States. From their description of damage we recognized this insect as being present in Maine in 1974. Mutuura (8) described the new species as Dioryctria resinosella and reported it infesting new shoots and cones of red pine in Ontario, Minnesota, Wisconsin and Maine. At the present time D. resinosella is not sufficiently abundant to cause significant damage to the extensive red pine plantations in Maine. However, if populations of this insect increase over time in response to the increased acreage of red pine or because of other factors, it could become an economically important species. The purpose of this research was to study the life cycle and behavior, mortality factors, the insect's impact on red pine plantations in Maine, and to rear the insect in the laboratory.

MATERIALS AND METHODS

In 1978, study areas for D. resinosella in young red pine plantations were chosen in Twp. 30, Wash. Co.; Lagrange, Penobscot Co.; and Twp. 40, Hancock Co. (Fig. 1). Trees ranged in size from 2-6 meters. Mature, natural red pine was present in all areas. Most of the work was carried out in Twp. 30, Wash. Co.

In August 1979, a brief survey of the distribution of D. resinosella in Maine was conducted. Both natural areas and plantations were observed.

The percentage of trees infested by D. resinosella in Twp. 30 on trees of various heights was determined in July 1978. Eleven plots of 100 trees each were chosen at random from several plantations; infested terminals were counted and tree heights were recorded.

The life cycle and biology were studied through field observations and laboratory rearing. New shoots suspected of containing larvae of D. resinosella were placed in airtight, .68 l (24 oz.), waxed cardboard

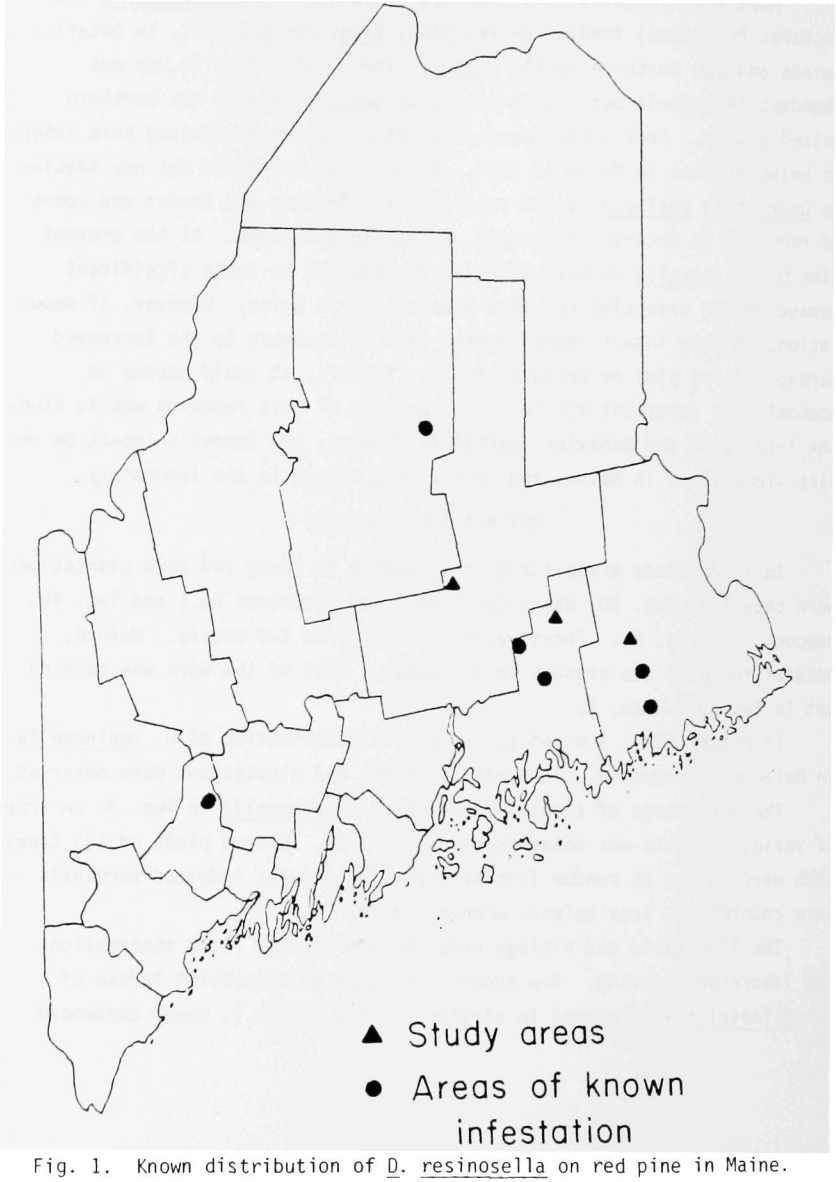

Fig. 1. Known distribution of D. resinosella on red pine in Maine.

containers, 17 cm in height and insects were reared in an incubator at 21.5 ± 1°C., with a 16:8 hour photoperiod. The bottom of a petri dish was used as a top for these containers to facilitate observations.

In July 1978, 25 trees with terminals damaged by D. resinosella were marked. In July 1981, these same trees were examined to determine damage to tree form.

In late June through early July 1979 1981, approximately 700 damaged terminals and laterals were collected. Insects in this material were reared in the laboratory in the same manner as mentioned above to obtain information on parasites and to procure moths for mating and oviposition studies. Fresh red pine shoots were added when necessary. Dates of pupation, adult emergence, and length of pupal period were recorded for both males and females. Pupal sex was determined using the method described by Jennings (5). After emergence in 1979, the damaged shoots were dissected and dead larvae and pupae were counted. The amount of feeding was measured and the feeding pattern was observed. Following moth emergence in 1980 and 1981, the damaged shoots were dissected and the number of empty shoots recorded to determine percentage inhabited.

On 2 July, 1981, four trees approximately 3 meters in height with terminals attacked by D. resinosella were selected to determine the pupation site. To determine whether or not they pupated in the litter, a fine mesh wire screen cage was placed around the base of each tree. The cage was packed with soil at the edges to prevent larvae from escaping and for cage stability. Sheets of acetate were stapled inside the cage at the top of the screen to further prevent larval escape. Because there was only one insect per tree, additional larvae were added to each tree by tying infested shoots to branches. Three trees had seven additional infested shoots attached and one tree had three. On 16 July, the trees and litter in cages were examined and pupation sites were recorded. Larvae preparing to pupate were preserved in 70% alcohol. Pupae and dead larvae were collected and returned to the laboratory for rearing of moths and parasites.

On 29 June, 1981, 11 infested shoots were placed in a screen cage (51x51x20 cm) in Twp. 30 to determine the date of adult emergence in the

field. The cage was located on the ground in partial shade and observed twice a week. The cage was later moved to the University Forest, Stillwater, Penobscot Co. on 24 July and observations continued until emergence.

In late July 1980 and 1981, rearing of D. resinosella was attempted in the laboratory. Twenty-one 3.78 l (one gallon) jars were used as rearing containers and a varying number of males and females were placed in each. Each jar contained: 1. paper towels which were moistened each day to provide humidity; 2. adult food source of cotton moistened with a saturated sugar-water solution or a honey-water solution; 3. cheesecloth to cover the mouth of the jar and to provide an oviposition site. In addition, 12 of the jars contained two red pine stems each for alternate oviposition sites. Pupae placed in each jar were about the same age to insure that males and females would emerge on approximately the same date. In 1980, rearing jars were kept at room temperature; in 1981, jars were kept in an incubator at 21.5 $\pm$ 1°C., with a 16:8 hour photoperiod.

To allow for more adult movement, three screen cages (51 x 51 x 20 cm) were also used for mating purposes. One cage was set up in the laboratory and two cages with red pine stems for oviposition were placed on the ground in partial shade in the University Forest.

After mating and oviposition were completed, jar contents and cages were examined for fertile and infertile eggs. Fertile eggs on red pine stems and cheesecloth were placed in desiccators with a saturated solution of NaCl, producing about 75% relative humidity at 21.5 $\pm$ 1°C. (Wexler and Hasegawa 11). Eggs remained in desiccators until first instar larvae had spun hibernacula, a period of several weeks. The desiccators were moved to 0°C. in early September. In 1980, the cold treatment period was four months; in 1981, 2, 3, and 4 1/2 month cold treatment periods were used. Following cold treatment, red pine stems and cheesecloth were placed either at room temperature (1980) or in an incubator at 21.5 $\pm$ 1°C. (1981), and observed daily for emerging first instar larvae. Hibernacula were examined to determine the instar of diapausing larvae. After larval emergence ceased, red pine stems and cheesecloth were examined to determine the number of eggs and hibernacula present.

First instar larvae were reared individually in fifty 56.7 ml (2 oz.) plastic cups containing artificial spruce budworm diet (Grisdale 3). The diet was changed and scarified about every two weeks. Number of instars was determined by counting exuvial head capsules found in the cups. At least one larva of each instar was collected and preserved by freezing in water. Only first and fifth instar larvae were used for larval descriptions.

Thirteen diet cups were used to determine if larvae were cannabalistic under rearing conditions; eight cups contained two larvae, four cups contained three, and one cup contained four. Cups were examined every two weeks for evidence of cannabalism.

The mean duration of larval and pupal development for laboratory reared D. resinosella was determined by recording the dates of larval emergence, pupation, and adult emergence.

Parasitized larvae and pupae of D. resinosella collected from the field were placed in 56.7 ml (2 oz.) plastic cups and held in a desiccator at about 75% relative humidity.

Other associated lepidopteran larvae found in mines of D. resinosella were reared in the laboratory in cups of the same type containing spruce budworm diet.

RESULTS AND DISCUSSION

Distribution

The known distribution of D. resinosella in Maine follows a band of red pine through Washington, Hancock, and Penobscot Counties, and an isolated infestation was found in Leeds, Androscoggin County. Figure 1 shows where infestations occurred in 1978. The insect appeared to be more abundant in plantations in Twp. 30, Washington Co. Other infestations occurred on natural red pine near Pickerel Pond in Twp. 32, Hancock Co.; in plantations in Lagrange, Penobscot Co.; and Twp. 40, Hancock Co. near Crystal Pond. Small numbers of D. resinosella were found in a plantation of 3-5 meter trees in Leeds, Androscoggin Co.; in a plantation of 5-10 meter trees in Twp. 25, Washington Co.; and in a plantation of young trees in Columbia Falls, Washington Co. Damage which appeared to be caused by D. resinosella was observed on natural red pine in Baxter State Park, but

damaged shoots collected did not contain larvae. No infestations were found in large areas of natural red pine in Twp. 11, Range 14, Aroostook Co. or at Cathedral Pines in Eustis, Franklin Co. Pines of all ages were abundant in both areas. No infestations were found in approximately 20 other young plantations in central and southern Maine.

Relation of Tree Height to Infestation Rate

Table 1 shows the percentage of trees infested by *D. resinosella* in several plantations of varying tree height. Infestation was low in plantations of small trees, and in most instances only one insect was found per tree. Infested terminals were difficult to observe on trees taller than 3 meters, so percentage of infestations is probably higher than shown for the 3.6 and 5.4 meter height classes. Infestations occurred on large trees but quantitative data were not collected.

Life Cycle and Biology

The life cycle is diagrammed in Fig. 2.

Larvae

Eggs hatch from mid to late August, approximately one week after being laid. First instar larvae enter an obligate diapause without feeding and, based on observations in the laboratory, overwinter in hibernacula spun beneath bark scales.

First instar larvae probably emerge in May (exact date unknown) and mine two or three shoots during their lifetime. In early to mid-June, small larvae were found in small lateral shoots, 3-6 cm in length in the mid-upper crown of trees (Fig. 3). Several of these larvae collected from small laterals were reared and proved to be adults of *D. resinosella*. Larvae entered near the base of the shoot and mined almost to the tip, killing the shoot. Infestations were light and usually only one larva was found per tree. Usually only one lateral was attacked per tree, but occasionally two laterals were damaged. The feeding pattern was variable in subsequently infested laterals, but most often larvae entered the shoot 2-4 cm from the tip, mining upward into the terminal bud and then down, 3-7 cm below the entrance hole. Frass was packed into the tip and pushed out the entrance hole. The tip later died and turned brown. By late June

Table 1

Percentage of trees infested by *D. resinosella* in young red pine plantations of varying heights in Twp. 30, Maine, July 1978. Each plot contained 100 trees

Average height of plot trees in meters	Percentage of trees with infested terminals
1.2	3
1.5	1
1.8	1
1.8	4
2.4	9
2.4	12
3.0	14
3.0	35
3.6	10
5.4	10

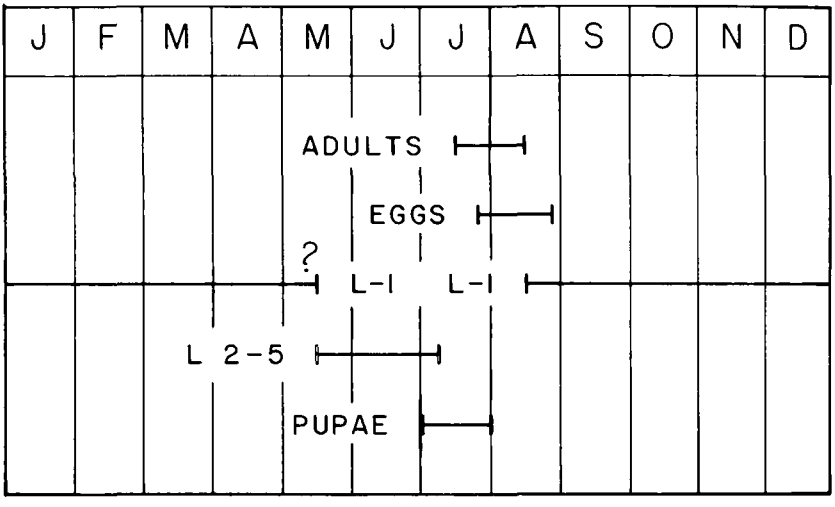

Fig. 2. Life history of D. resinosella from field observations and laboratory rearings.

Fig. 3. Small lateral shoot attacked by D. resinosella showing orange pitch and frass.

and early July, larvae had entered the terminal (Fig. 4) or occasionally a lateral in the terminal whorl. Occasionally larvae did not attack a lateral initially but attacked the terminal first, then attacked a large lateral shoot lower in the crown. Approximately half of the larvae entered terminals near the tip, their mines going into the terminal bud. Others entered about 12 cm from the tip and mined upwards or in both directions, but mines did not reach the terminal bud. Mines averaged 10 cm in length. Rarely were two larvae found in different parts of the same terminal.

Pupae

Mature larvae leave the mines in late June and early July. The pupation site is variable. Pupae were found in mined terminals (Fig. 5); under bark scales (Fig. 6), 15-100 cm above the ground; in the litter, 3-8 cm deep; and in the scaly material of the crotch of the terminal whorl of branches.

Adults

Emergence in the field cage occurred from August 3-7. Females oviposited under bark scales in the branches provided; a single egg in each location. Since populations were light, adults and eggs were not observed under natural conditions in the field.

Damage

By mid-July, the upper portion of infested terminals wilted, turned brown (Fig. 7), and some had broken from the trees. The following year 63 percent had terminals that survived by forming adventitious buds below the point of attack (Fig. 8). The effects of shoot damage on tree growth three years after attack are shown in Figs. 9, 10, and 11. Eighty-four percent of the trees with terminal damage had laterals that assumed dominance; 32 percent of these trees had dead leaders. Such trees only had a small crook. Sixteen percent suffered permanent growth damage, with two laterals assuming dominance, thus causing a fork. Three trees (12%) were attacked at least twice during the study.

Damage to terminals was not as serious as that caused by white pine weevil, *Pissodes strobi* (Peck), which may destroy several years' growth. *D. resinosella* larvae only damage part or all of the current year's growth.

Fig. 4. Terminal attacked by D. resinosella showing pitch, frass, and dead tip.

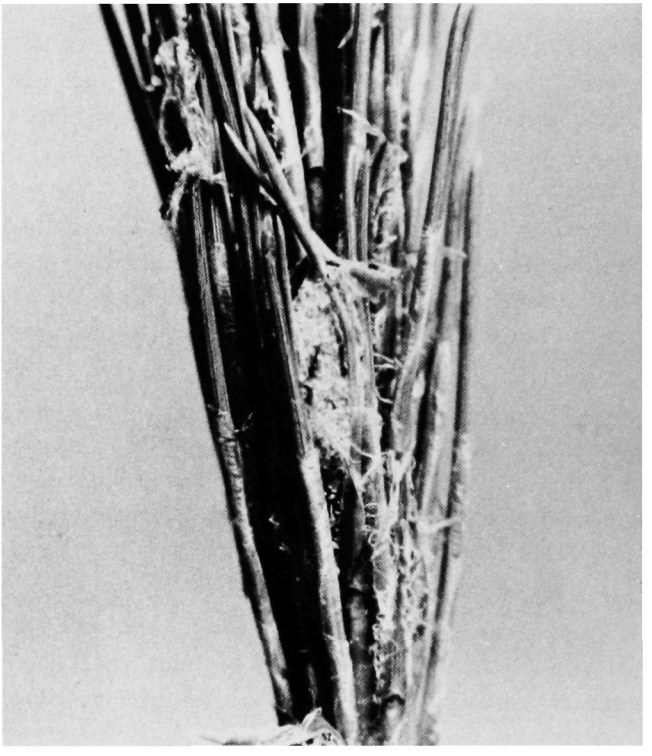

Fig. 5. Cocoon of D. resinosella in mined terminal shoot.

Fig. 6. Cocoon of D. resinosella beneath bark scales.

Fig. 7. Red pine terminal attacked by D. resinosella.

Fig. 8. Red pine terminal showing budding below the point of previous year's attack by D. resinosella.

Fig. 9. Terminal shoot damage three years after attack on red pine by D. resinosella; one lateral has assumed dominance, the center leader (arrow) is dead.

Fig. 10. Terminal shoot damage three years after attack on red pine by D. resinosella; one lateral has assumed dominance, the center leader (arrow) is still alive.

Fig. 11. Terminal shoot damage three years after attack on red pine by D. resinosella; two laterals (arrows) are growing equally, but the center leader is dead.

The damage of D. resinosella can be distinguished from that of the commonly encountered red pine cone beetle, Conophthorus resinosae Hopkins, because shoots attacked by that species crook sharply in the middle, and only clear pitch exudes from the gallery.

Laboratory Rearing

Pupation of Field Collected Larvae and Adult Emergence

At 21.5 ± 1°C most pupation occurred between 3-15 July. Males emerged 1-2 days before females.

Eggs

Oviposition began about one week after moth emergence. Fertile eggs were usually deposited under bark scales or on cheesecloth. Infertile eggs were deposited on any available surface. Data were collected on 17 females in 1980 and 24 females in 1981. Eggs laid per female in rearing jars ranged from 1-114 with the $\bar{X}$ eggs/female 34.5 (including females in laboratory and field cages) in 1980 and 54.6 in 1981. However, mean fertile eggs per female were only 5.1 in 1980 and 36.0 in 1981.

Larvae

Eclosion began about one week after oviposition. Empty hibernacula were difficult to find on the pine stems. Therefore, the percentage of larvae determined to have emerged was probably not sufficiently accurate to determine if the varying length of cold treatment was influential. Emergence varied from 59 to 72 percent.

Eggs and egg chorions were apparently fed upon by first instar larvae; however it is not known whether feeding occurred before hibernacula were spun or after emerging from hibernacula.

Males and females were approximately equal in numbers in the 50 diet cups. The mean length of larval development on spruce budworm diet was 40 ± 6.0 days for males and 41 ± 2.9 days for females at 21.5 ± 1°C. D. resinosella larvae have five instars based on the number of head capsules found in 50 diet cups.

Cannabalism occurred in all cups with more than two larvae, but only in two of eight cups containing two larvae. Frass of larval feeding on

artificial diet is yellowish in color. Evidence of cannabalism was the presence of larval remains and black frass.

Pupae

Mean pupal period for larvae reared on artificial diet was 16 ± 1.3 days for males and 16 ± 1.9 days for females at 21.5 ± 1°C.

Adults

Adults from larvae reared on artificial diet failed to lay fertile eggs.

Description of Life Stages

Eggs

Eggs are about 1 mm long and have a pattern of sculpturing on the chorion (Fig. 12) which may be species specific. Fertile eggs are reddish-pink and infertile eggs are pale yellow in color.

Larvae

First instar larvae are about 2 mm long. The body is reddish-brown with a dark dorsal midline and two light subdorsal lines. The head capsule is brown and slightly wider than the body. The thoracic shield is also brown. Fifth instar larvae are 14-17 mm long. The body is greenish-gray to greenish-purple on the dorsal surface and light green on the ventral surface. A faint dark dorsal midline is present. The head capsule and thoracic shield are brown.

Pupae

Pupae are 12-15 mm long; females are usually larger than males. Immediately after pupation, wing pads and legs are green and the abdomen brown. Pupae turn completely brown when nearing completion of development.

Adults

Adults have been described by Mutuura (8).

Natural Control

Few parasites were reared from mature larvae and pupae. Rates of parasitism for 1979-1981 are shown in Table 2. The relative abundance of parasite species is shown in Table 3 for 1979 and 1981.

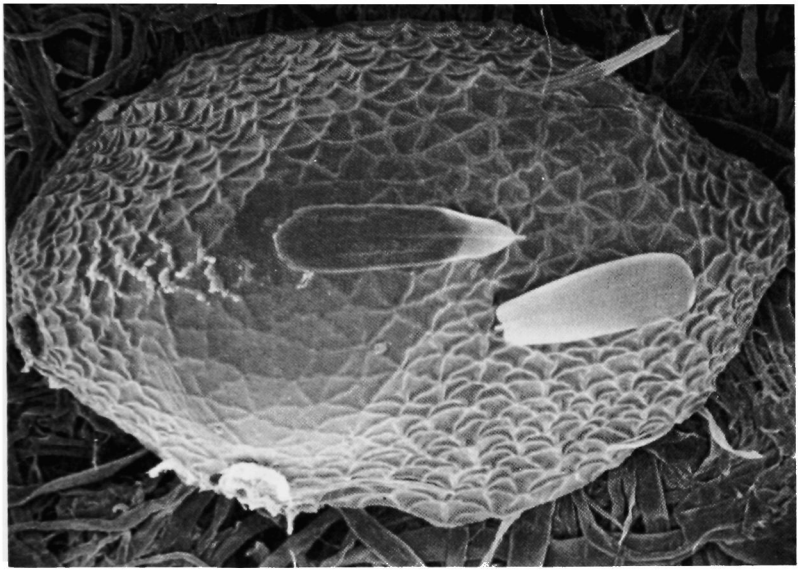

Fig. 12. Scanning electron micrograph of D. resinosella egg, 100X.

Table 2

Percentage parasitism of mature larvae and pupae of *D. resinosella* in Maine

Year	Number of *D. resinosella* Parasitized / Number of *D. resinosella* Collected	% Parasitism
1979	9/124	7.3
1980	0/48	0.0
1981	11/197	5.6
Total	20/369	5.4

Table 3
Parasites reared in the laboratory in 1979 and 1981 from mature larvae and pupae of *D. resinosella* in Maine

Species	Number of *D. resinosella* Parasitized	Number of Parasites/Host	Host Stage Emerged From
1979:			
Tachinidae			
Phrynofrontina prob. n. sp.	3	1	Larva
Braconidae			
Apanteles fumiferanae	1	1	Larva
Ichneumonidae			
Exeristes comstockii	1	1	Larva
Eulophidae			
Elachertus pini	3	1-11	Larva
1981:			
Braconidae - Rogadinae			
Undetermined Adult*	1	1	Larva
Ichneumonidae			
Exochus turgidus	1	1	Pupa
Ichneumon brunneri	1	1	Pupa
Pterocormus dioryctiae	1	1	Pupa
Scambus sp.	2	1-2	Larva
Undetermined Larvae	4	1	Pupa
Eulophidae			
*Elachertus pini**	2	4-7	Larva

* Both species parasitized the same host larva.

Phrynofrontina prob. n. sp. pupated in the pitch and frass covering the entrance hole of the shoot, after leaving the host caterpillar. It left an opening in the pitch from which to emerge. Phrynofrontina sp. was previously reported from D. amatella (Hulst) and D. clarioralis (Walker) (2). Elachertus pini Gahan emerged in numbers ranging from 1-11 parasites per larva. This species pupated externally on the host and was the only species reared in both years; it was the most abundant species found. Krombein, et al. (6) also reported this parasite from Dioryctria sp. Apanteles fumiferanae Vier. spun its cocoon on the outside of the shoot in the laboratory. Krombein, et al. (6) reported this parasite from D. abietella (D. and S.) and D. reniculella (Grote). The undetermined species of Braconidae, subfamily Rogadinae, emerged from a host larva that was also parasitized by E. pini. Exochus turgidus Holmgren is an internal parasite. Neunzig, et al. (9) reported this parasite from D. amatella and Krombein, et al. (6) reported it from D. disclusa Heinrich, D. auranticella (Grt.) and D. reniculella. Exeristes comstockii (Cr.) was an external parasite. Krombein, et al. (6) reported it from D. zimmermani, D. amatella, D. auranticella, and D. clarioralis (Wlk.). Lyons reported E. comstockii from D. disclusa. Ichneumon brunneri Rohwer is an internal parasite, and required a 2 1/2 month cold treatment in the laboratory before emerging. Lyons (7) reported it as the most abundant and important parasite of D. disclusa in Ontario, where it overwinters as a larva in the host pupal case and emerges as an adult in the spring. Krombein, et al. (6) reported I. brunneri from D. auranticella and D. zimmermani. Literature indicates I. brunneri only parasitizes species of Dioryctria. Pterocormus dioryctiae (Heinrich) is an internal parasite. Krombein, et al. (6) reported this parasite from D. reniculella, the only known host previous to this report. Scambus sp. is an internal parasite. In one instance, two adults emerged from a single host larva. Four ichneumon parasites did not complete development, and therefore were not identified.

A further breakdown of percentage parasitism of D. resinosella in 1981 as shown in Table 2 is shown in Table 4. Three parasitized Dioryctria larvae were obtained from 182 infested shoots collected from 29 June-1 July, a parasitism rate of 1.6%. On 16 July, seven parasitized pupae

Table 4

Percentage parasitism of mature larvae and pupae of *D. resinosella* in 1981

Date Collected	No. of *D. resinosella* Parasitized / No. of *D. resinosella* Collected	% Parasitism
June 29-July 1	3/182	1.6
July 16	8/15	53.3

and one parasitized larva were obtained from 15 infested shoots used in the pupation site study, yielding a parasitism rate of 53.3%. Apparently pupating larvae which are exposed when descending the tree or constructing a cocoon and possibly the pupae themselves are subject to greater parasitism than larvae feeding inside the shoot.

The only predator of D. resinosella found was Thanasimus undulatus (Klug) (Coleoptera: Cleridae). The beetle larva was found feeding on a pupa under bark scales.

Eggs and 1st-2nd instar larvae were not observed in the field, thus mortality factors for these life stages could not be assessed. However, assuming that at least the mean number of fertile eggs oviposited per female in the laboratory in 1981 (36.0) is also deposited in the field, and because the number of infested trees is low and usually only one larva successfully attacks a tree, mortality during these early life stages probably is high and has a large impact on the population of D. resinosella.

Associated Insects

Two species of Lepidoptera were found inhabiting mines of D. resinosella in the current study. The most abundant species was D. abietivorella (Grote). Thirteen larvae were collected from Twp. 30 and one was collected from Baxter State Park. Carlson and Butcher (1) often found this species inhabiting mines of D. zimmermani. Hedlin, et al. (4) stated that in addition to feeding on cones, D. abietivorella larvae are apparently attracted to pitch and will enter a wound and begin feeding.

D. abietivorella can easily be distinguished from D. resinosella as follows: larvae found inhabiting mined shoots were smaller (i.e. an earlier instar) than mature D. resinosella larvae at the time of collection. D. abietivorella larvae were not capable of making a mine of the size they were inhabiting and frass size was smaller than that made by mature D. resinosella larvae. Damaged shoots inhabited by D. abietivorella showed signs of browning and drying out when collected, indicating that the mine was not freshly made. Emergence of D. abietivorella adults in the laboratory was approximately one month later than that of D. resinosella.

Early instar D. abietivorella larvae found in the field were approximately 7 mm long. The body is dark amber on the dorsal surface and light amber on the ventral surface, with a faint light dorsal midline and two faint light subdorsal lines. The head capsule and thoracic shield are dark brown. The head capsule is not wider than the body as in young larvae of D. resinosella. Pupae are approximately 12 mm long and are slightly wider than pupae of D. resinosella, with the head capsule more rounded. The coloration is similar to D. resinosella. Descriptions of eggs, mature larvae, and adults of D. abietivorella are found in Hedlin, et al. (4)

The other insect found in mines of D. resinosella was an unidentified species of Tortricidae. Four larvae were found in Twp. 30. This species can be distinguished from D. resinosella as follows: mature larvae are much smaller than those of D. resinosella, being approximately 9 mm long. The body is greenish-blue with a brown head capsule and black thoracic shield. The gonads are visible through the integument. Pupae are 5-6 mm long and colored green with brown highlights. Each abdominal segment is encircled by two rows of dark brown spines. Pupae of this undetermined tortricid required a three month cold treatment in the laboratory; only one adult emerged. The adult is 4 mm long with a wingspan of 11 mm. The fore wings are spotted dark brown and grey; the hind wings are grey and unmarked. This specimen could not be identified and is in the collection at the University of Maine at Orono.

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