

R. O. Warren
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A PINE SAWFLY
Neodiprion Pratti Pratti
IN VIRGINIA



Virginia Division of Forestry



Department of Conservation and Economic Development

A PINE SAWFLY
NEODIPRION PRATTI PRATTI (Dyar)
IN VIRGINIA

By

Caleb L. Morris, William J. Schroeder and Marvin L. Bobb^{1/}

^{1/} Respectively, Chief and Assistant Chief, Forest Insect and Disease Investigations, Virginia Division of Forestry; and Entomologist, Virginia Agricultural Experiment Station, Piedmont Fruit Research Laboratory, Charlottesville, Virginia.

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Introduction

Two successive years of severe defoliation by the pine sawfly *Neodiprion pratti pratti* (Dyar) in Virginia raised expressions of concern regarding the potential seriousness of this pest (Fig. 1). How many years of severe defoliation could the native shortleaf and Virginia pines withstand? Would the pest—already known to feed on loblolly pines—cause extensive defoliation of this species in the Coastal Plain? How could we predict population density from year to year? Should control measures be instituted? Because of the lack of past experience with this insect, there were no direct answers to these questions.

At the suggestion of State Forester George W. Dean, a "Technical Committee on the Virginia Pine Sawfly" was organized in July 1959. The Virginia Division of Forestry, the Department of Entomology and Extension Entomology of Virginia Polytechnic Institute and the State Entomologist were represented on the Committee.

Plans were laid to investigate the biology and control of this native pest. V. P. I. assumed the responsibility for a study of the insect parasites and contributed supplemental data on predators and adult emergence. The Virginia Division of Forestry conducted the remainder of the study.

This bulletin is the result of that cooperative investigation.^{1/}

^{1/} The valuable assistance of Kenneth A. Knox, Forest Insect and Disease Investigations, Virginia Division of Forestry, in both field and laboratory on this project is acknowledged.



Figure 1. An 18-year old stand of shortleaf pine in the southern Piedmont almost completely stripped of its foliage in early May 1958. Stands in this condition appear to have been killed by wildfire.

History Of The Outbreak

Defoliation by the sawfly *N. pratti pratti* was first noted in Maryland and northern Virginia in 1955 (21). Activity by this same sawfly in central Piedmont Virginia was reported by Division of Forestry personnel in April 1957. Noticeable defoliation of shortleaf and Virginia pine occurred at that time in occasional stands in Louisa, Nelson, Albemarle, Culpeper, King and Queen, Buckingham, Cumberland, Gloucester and Middlesex Counties. Larval activity in Halifax and Mecklenburg Counties was also reported in 1957 by extension entomologists at V. P. I.

Both 1958 and 1959 could be considered peak epidemic years in central and southern Piedmont Virginia when defoliation averaged 50%. By 1959 defoliation in pine and pine-hardwood forest types was evident over an estimated 3,116,000 acres in the Commonwealth (7), and had extended eastward to those coastal areas where Virginia pine was present (Fig. 2). Populations increased in the eastern edge of the epidemic area in 1960 but dropped noticeably in the central and southern Piedmont. By 1961 a noticeable decline in larvae populations was evident in the coastal area. Severe defoliation (50-100%) was evident in 1962 only in occasional stands. By spring 1963 scattered colonies could be found active throughout the original area of infestation (Fig. 3); the infestation was definitely on the wane in the eastern part of the State, with defoliation in all counties where the sawfly had been active now averaging less than 15%. In a few Piedmont counties populations increased somewhat over the level of the previous year. Exception to the generally abrupt drop following two years of peak populations was noted in the vicinity of the James River drainage of Piedmont Virginia and in the vicinity of the John H. Kerr Reservoir (Buggs Island Lake).

The infestations in Maryland & North Carolina have been described (11). The rise and fall of populations in North Carolina closely followed that noted in Virginia.

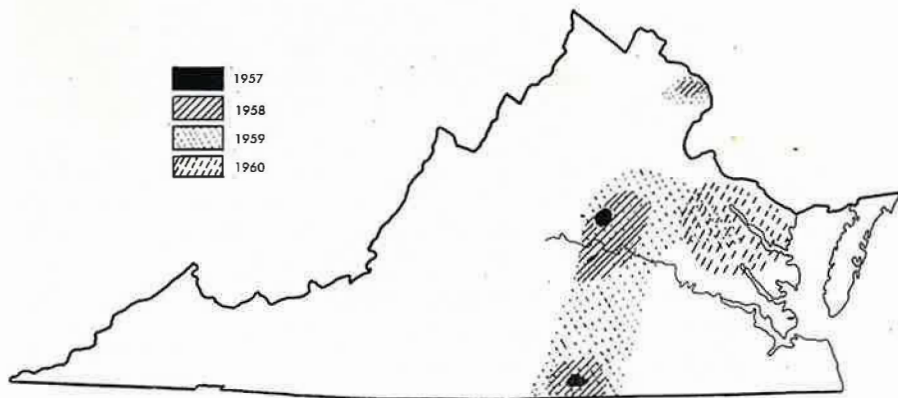


Figure 2. Changing pattern of the epidemic of *N. pratti pratti* in Virginia 1957-1960.

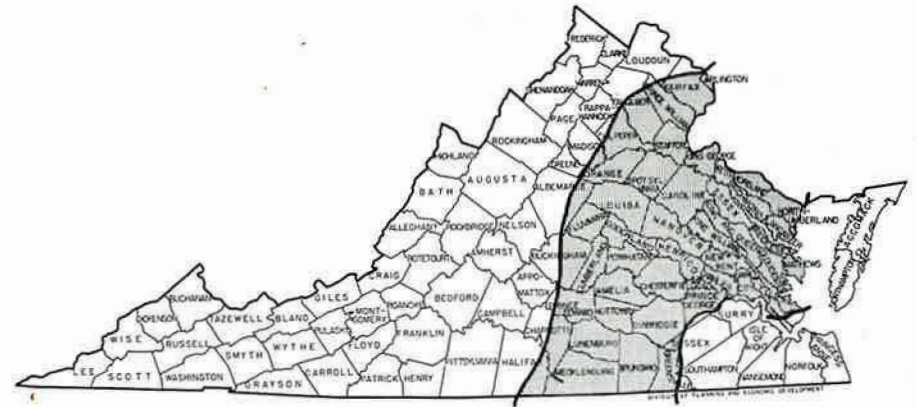


Figure 3. Area of Virginia in which defoliation by *N. pratti pratti* was noticeable during the period 1957-1963.

Biology

The study of the biology of *Neodiprion pratti pratti* was considered of primary importance. Only brief notes were available on its life history and no information was available on the importance of natural control. To answer the questions put forth in the "Introduction", studies and observations were made from 1958 to 1963 on the biology of *N. pratti pratti* in the field and in the laboratory.

DISTRIBUTION

Neodiprion pratti pratti (Dyar) occurs in the District of Columbia, Maryland, Virginia and North Carolina (1). This sawfly has also been reported in Ohio (2), Indiana (17), and in eastern Kentucky, Illinois, and New Jersey (18).

NOMENCLATURE

As reported by Ross (17), adult females of *Neodiprion pratti pratti* (Dyar) reared from *Pinus taeda* in Virginia by Dr. Hetrick matched with types of both *pratti* and *dyari*. Ross therefore feels certain that *pratti* is the prior name for this species formerly called *dyari*.

According to Ross (17) the species *pratti* can be divided into three geographic units each differing from the other in average characters. He therefore proposed that these three segregates (*pratti*, *banksianae*, *paradoxicus*) be considered as subspecies.

HOSTS IN VIRGINIA

During the period of this study, *N. pratti pratti* was noted feeding on the following native pine species:

Virginia pine, <i>Pinus virginiana</i>	preferred
Shortleaf pine, <i>Pinus echinata</i>	preferred
Pitch pine, <i>Pinus rigida</i>	secondary

Loblolly pine, *Pinus taeda*.....secondary
In the laboratory, larvae of *N. pratti pratti* have been reared successfully on:

Longleaf pine, *Pinus palustris*

Red pine, *Pinus resinosa*

Norway spruce, *Picea abies*

In limited feeding trials, larvae of *N. pratti pratti* failed to complete their development successfully on eastern white pine, *Pinus strobus*, and Douglas fir, *Pseudotsuga menziesii*.

LIFE STAGES

EGG

Description—The egg is bright yellow, crescent-shaped, moderately pointed and smooth when dissected from the female, changing to a light yellowish-white soon after oviposition. Eggs removed from adult sawflies averaged 1.64 mm in length and 0.46 mm in width. Each egg is deposited individually within a slit made by the female along the flat side of the pine needle. A slight, gradual swelling becomes evident in the month following deposition, development is slowed during the winter months and progressive swelling is again evident the month before hatching in the spring. Just prior to hatching the swollen eggs, confined in the needle tissue, measure 1.6 mm x 0.7 mm x 0.8 mm (Fig. 4).

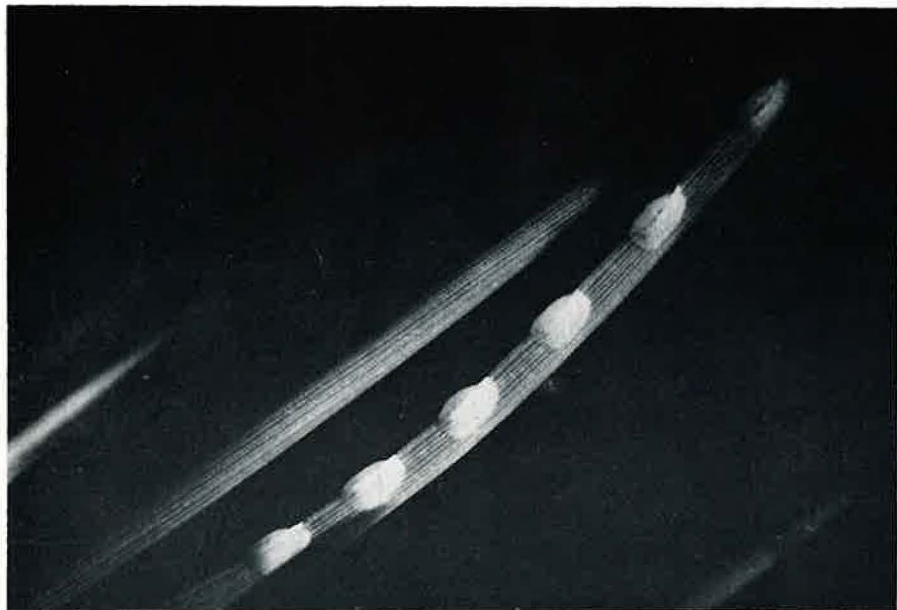


Figure 4. Swollen eggs of *N. pratti pratti* just prior to hatching in early April.

Development—Eggs brought into the laboratory one week after deposition in November and held at 75°F. hatched in 14 days. Eggs collected in January hatched in 10 days under the same conditions, while eggs collected during February hatched in 9 days, indicating

a progressive development of the embryo from the time of oviposition. Four to six days prior to hatching, an eye-spot oriented toward the base of the pine needle becomes visible through the chorion and the dead needle tissue. Forty-eight hours prior to hatching the egg protrudes 0.30-0.35 mm above the needle surface; 24 hours before hatching the developing larva becomes grey in color, and segmentation becomes evident. The larva then twists within the egg until the mandibles are brought in contact with the protruding chorion and hatching takes place.

Under field conditions eggs began hatching in central Virginia in 1961, 1962 and 1963 at the time the leaves of yellow poplar were becoming apparent, and the expanding main buds on exposed lateral branches of sapling-sized Virginia pine averaged 1.4 inches in length. Under optimum conditions, all viable eggs would be expected to hatch within six days.



Figure 5. Laboratory rearing of individual colonies of *N. pratti pratti*. The small dishes contain a saturated solution of sodium acetate to control humidity.

Factors Affecting Hatching—To determine the inter-relationship of temperature, light and humidity and their effects on egg hatching, laboratory rearing was conducted. Egg-bearing Virginia and shortleaf pine twigs were washed with a 1:10 solution of Clorox and rinsed. The severed end of the twigs were placed in water under battery jars where the humidity was chemically controlled (Fig. 5). Eggs collected in early February 1961 and held at 75°F. and 75% relative humidity hatched in nine days, whether subjected to 12-hour light or held in complete darkness. This experiment was repeated in late December 1962 when eggs collected on December 20 were subjected to 0, 10 and 14 hours of light. All hatched

in 9-10 days. It appears that temperature is the primary factor regulating egg hatch. Humidity, ranging between 12% and 75%, did not affect egg hatch.

Viability—To determine egg viability, a total of 663 eggs were collected at the time of hatching in 1961 from loblolly, shortleaf and Virginia pine and observed in the laboratory. Larvae emerged successfully from 94% of the eggs that season. The remaining eggs never developed into larvae or the larvae failed to complete emergence.

In 1962 egg hatch was 84% for shortleaf pine, 68% for Virginia pine, and 75% for loblolly pine. Emergence in many of the samples

of Virginia pine was reduced by excessive browning of the needles as the result of egg deposition.

Corresponding figures for 1963 were: 90% egg hatch on short-leaf and 84% on Virginia pine.

LARVA

Description—Newly hatched larvae range from 2.7 to 3.5 mm in length and average 3.1 mm (Table 1), and are pale green with a whitish, translucent head capsule (Fig. 6). A dark brown circle surrounds the simple eye. Within an hour the color of the head capsule changes, progressing through shades of grey to a deep, shiny black; this color change is repeated following each molt. Feeding begins 3-5 hours after hatching at a point about one-half inch below the needle tip with groups of 2-15 larvae consuming the fleshy outer portion of the needle, leaving the inner vascular tissue. This type of feeding continues for the first two instars; thereafter the larvae are able to consume the entire needle, except for the basal portion within the sheath. Larvae may occasionally feed on portions of the developing buds and may consume the bark in irregular patches on the twigs. During unusually cool or wet periods in the early spring the larvae cease feeding and congregate at the base of the needles until conditions are again favorable.



Figure 6. Newly hatched larvae are pale green with a translucent whitish head capsule; within an hour the head capsule has turned a shiny black.

Table 1. Larval Length and Head Capsule Measurements by Instar.

Instar	Larval Length	Head Capsule Width	
	Average (mm)	Average (mm)	Range (mm)
1st	3.1	0.61	0.51-0.68
2nd	7.4	0.90	0.78-0.98
3rd	12.8	1.14	1.03-1.28
4th	16.0	1.45	1.30-1.62
Preupal Male		1.44	1.36-1.60
5th (Females only)	22.8	1.74	1.60-1.95
Preupal Female		1.73	1.65-1.80

The pattern of the stripes on mature larvae is exceedingly variable (Fig. 7). Generally, the larva is pale green with four grey to black strips extending from the prothorax to the anal segment (Fig. 8). These dark stripes become strongly apparent on some larvae fol-

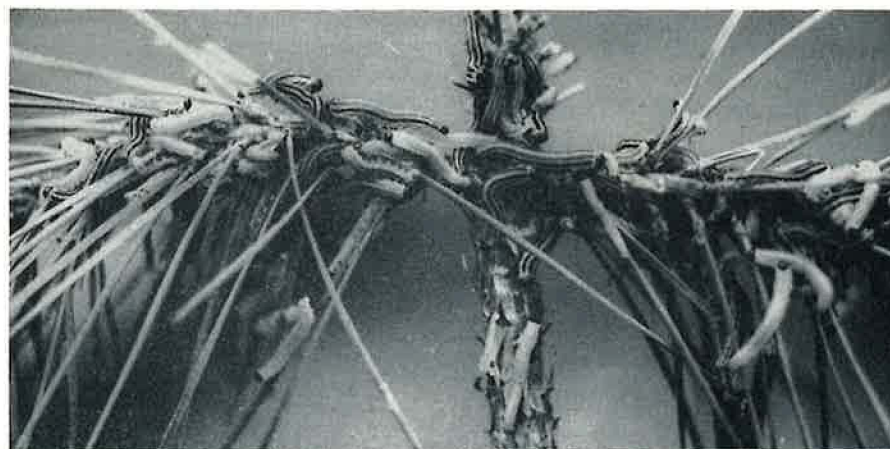


Figure 7. Full-grown larvae of *N. pratti pratti* exhibit a variable color pattern.

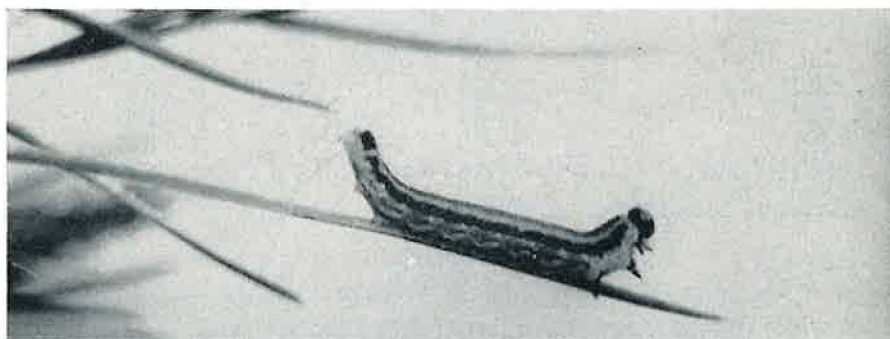


Figure 8. A mature larvae of *N. pratti pratti* in a characteristic position assumed when disturbed.

lowing the second molt. These are reportedly the male larvae (3). The two lateral stripes are suprspiracular, darker than the dorsal ones and sometimes discontinuous, appearing as a series of irregular black dots. The black dorsal patch on the anal segment may or may not be divided. Most larvae have a thin, dark subspiracular stripe which is often discontinuous or absent on the thoracic segments. The base of the prolegs is joined by a black line which may be discontinuous, extending from the first to the ninth abdominal segment. The ventral area of the mature larva is pale green with seven pairs of abdominal prolegs and an anal pair separated by a single abdominal segment.

Length of Larval Life—In the field the length of the larval period will vary considerably depending on weather conditions and temperature (Table 2). For example, cool, wet weather in late March and early April of 1961 caused a prolonged first instar lasting 14 days, whereas in 1960 most larvae completed the first instar in four days under normal weather conditions.

Table 2. Length of Larval Life as observed in Louisa County from 1958 to 1963.

Year	Hatching Date	Completion of Feeding		No. Days	
		Male	Female	Male	Female
1958	4/17		5/21		34
1959	4/ 1		5/20		49
1960	4/13	5/10	5/19	27	36
1961	3/27	5/ 8	5/16	42	50
1962	4/10	5/10	5/16	30	36
1963	4/ 1	4/26	5/ 5	25	35
			Average—	31	40

In the laboratory larvae were reared individually and in groups during the winter of 1961 and again in 1962. All larvae were reared at 66-76°F. at 75% relative humidity. A saturated solution of sodium acetate was used for humidity control. The length of the larval feeding period based on several hundred larvae was found to be 15-16 days for the male, and 17-19 days for the female. The duration of each larval stage was also determined.

Table 3. Duration of larval stages under laboratory conditions.

Instar	Average No. of Days	Range in Days
1st	3.5	3-6
2nd	4.0	3-9
3rd	4.0	3-6
4th	4.0	3-6
5th (females)	3.0	2-5

Average feeding period, male: 15.5 days; female: 18.5 days.

PREPUPA

Description—Male larvae develop through a series of four feeding instars while female larvae have five. After the final molt, the head capsule becomes light brown while the body and the thoracic regions become a dull brown with longitudinal grey stripes. The dorsal stripes are usually broken midway between the thorax and anal segment. The non-feeding prepupae then drop to the ground and crawl about before spinning cocoons in the duff. (In laboratory rearing the prepupae were active for a minimum of 4 hours and a maximum of two days before cocooning.)

Cocoon location and description—Male prepupae spin their cocoons primarily in the surface litter while females often cocoon in the soil as well as in and under the duff. Of 302 cocoons collected in Prince Edward County during 1960, only 1% of the males were found in the soil, whereas 42% of the female cocoons were present up to 2 inches deep in the sandy soil. The remaining cocoons were in the surface litter or only partially imbedded in the soil. During 1960 in Cumberland County 5% of the male cocoons were present in the soil, while 50-62% of the female cocoons in this area were found at a depth of up to 1.5 inches in the sandy soil. In clay soils cocoons are seldom found deeper than 0.25 inch. Soil moisture at time of cocooning affects cocoon location, with a greater number of the cocoons found above the soil line during wet seasons.

Female prepupae spin cocoons averaging 8.6 by 3.9 mm (range 8.2-9.4 long and 3.6-4.2 wide). The smaller cocoon of the male averages 6.6 by 2.9 mm (range 5.9-7.1 long and 2.6-3.1 wide). This size differential was utilized in determining sex ratio in 1962 (Table 4). The cocoons of both sexes are cylindrical with rounded ends, moderately shiny, smooth and tarnished bronze in color, becoming darker with age when in contact with the soil.

N. pratti pratti remains in the prepupal stage from mid-May until the latter part of September when they transform to pupae.

Table 4. Sex Ratio as Determined by Rearing Field-collected Colonies.

No. Males	No. Females	Ratio
1,052	1,421	0.74 to 1.00

PUPA

Description—The pupa is a uniform light tan with black compound eyes and three black ocelli. Diapause has been observed for the prepupae; of all cocoons collected during May and held in the insectary until adult emergence 1.8% remained in the prepupal stage in 1960, 1.9% in 1961, and 1.6% in 1962.

General—The prepupal and pupal stages of larvae reared in the laboratory under day-length of 10-14 hours lasted an average of 42 days for the male, and 40 days for the female (range male 27-58 days, range female 31-53 days). This constituted a considerably shorter cocooning period than the five month period which is normal for field populations.

Normal pupation can be halted if prepupae are refrigerated at 37°F. as late as mid-August. Refrigeration at a later date fails to retard pupation.

Moisture is a critical factor in the pupal stage. Many pupae die before transforming into the adult stage if moisture is too high. Conversely, if the cocoon becomes dry, adult emergence is severely hampered.

ADULT

Description — The adult female averages 8.7 mm in length, and is brown to brownish-black except for the ventral aspect of the abdomen which is brown with two longitudinal dark bands (Fig. 9). The yellow of the eggs is visible through the abdominal wall. The antennae are serrate, black and have 20 seg-



Figure 9. Adult female of *N. pratti pratti* with full complement of eggs.

ments. The legs may vary from light to dark brown with whitish areas on the basal portion of the trochanters and femur.

Adult males are black, smaller than the female, and average 6.2 mm in length. They are further distinguished by black, bipectinate antennae consisting of 20 segments. According to Hetrick (9), male adults of the Virginia pine sawfly cannot be distinguished from those of other species.

Emergence—Peak emergence of the adults usually occurs during the last week of October or the first week of November (Fig. 10). The highest daily emergence occurs on warm, sunny afternoons; very few adults emerge at night or on cloudy days. Emergence data are based on hundreds of cocoons collected from defoliated stands throughout the state.

Fecundity — When ready to emerge, the adult cuts a circular hole in the end of the cocoon (Fig. 16). The abdominal cavity of the female is filled with eggs at this time, and additional eggs are not formed. Fecundity for field-collected and laboratory-reared adults is shown in Table 5. To determine the effect of larval starvation on fecundity, several hundred larvae in the late third and

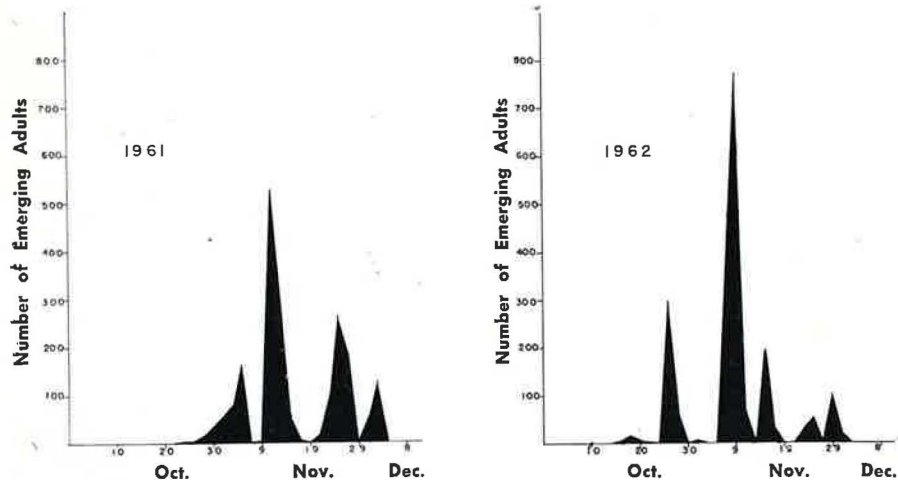


Figure 10. Peak emergence of adult males and females of *N. pratti pratti*, (1960-1962).

early fourth instars were deprived of food. Mortality of larvae, prepupae, and pupae was extremely high. Egg productivity was reduced 40% for the 15 survivors, when compared to fecundity of the average field-collected female for 1961 (Table 5).

Mating and Oviposition—Mating occurs soon after the adults escape from the cocoon. The males are quite active, while the female usually sits quietly on a needle and waits for the male to find her. The presence of a sex attractant in the female was indicated during caging studies. As observed in four pairs, copulation took from 16 to 37 minutes. Females apparently mate only once while the male may mate three or more times. Adults are positively phototropic and are most active on sunny afternoons.

Oviposition begins soon after mating. The female prefers to oviposit on needles exposed to the afternoon sun. The optimum temperature for egg-laying is from 50 to 60°F. Beginning at the base of the needle, the female carefully traverses its length, then backs down a short distance before making the first egg pocket. She then repeats the egg-laying process toward the tip of the needle. One or several false egg niches, or pockets void of eggs, are generally made prior to egg-laying. Of 150 Virginia pine needles examined, 126 had

Table 5. Fecundity of *N. pratti pratti* Under Field and Laboratory Conditions.

Year	Number of		Sample Source	No. of Eggs per Female	
	Females Dissected			Average	Range
1960	66		Field	66.4	31- 85
1961	15		Field	74.5	55- 88
1961	15		Lab (starvation)	44.5	15- 75
1961 (Apr.)	4		Laboratory	87.0	30-113
1962 (Jan.)	23		Laboratory	90.7	67-105
1962	20		Field	73.5	45-102

one niche below the first egg. On 19 of these needles, two false niches were present. A similar pattern was observed on shortleaf and loblolly pine. After an egg has been deposited, the female moves forward and repeats the egg-laying process. In some instances, additional false niches may follow the deposition of the last egg. The eggs are uniformly spaced, although infrequent irregularities may occur.

Rate of egg deposition is influenced by temperature. Sawing the egg pocket consumes the greatest portion of time. Number of eggs deposited (Table 6), and the place of oviposition along the needle, vary with the species of pine involved (Table 7).

Unmated females delay deposition of their eggs until near death; the majority die without laying any eggs. Unfertilized eggs hatch successfully and produce normal larvae.

Table 6. Number of Eggs Per Needle by Host Species.

Host Species	Number of Eggs			No. Needles Examined
	Max.	Min.	Avg.	
Shortleaf Pine	8	1	3.0	932
Virginia Pine	6	1	2.6	782
Loblolly Pine	15	1	4.9	607

Table 7. Position of Eggs on Needles of Host Pines.^{1/}

Species	Length of Needle	Base of Needle-1st egg	Distance Between Eggs				Last egg to end of needle	Number of Needles Examined	
			1st-2nd	2nd-3rd	3rd-4th	4th-5th			
Va. Pine	max.	66	54	8	7	7	7	32	200
	min.	30	10	2	2	3	3	3	
Shlf. Pine	avg.	46	31	4.4	4.1	4.0	4.0	7	200
	max.	114	73	8	9	7	7	40	
Lob. Pine	min.	44	16	2	2	2	3	3	173
	avg.	75	47	4.7	4.6	4.6	4.7	15	
Pine	max.	221	105	7	9	8	8	77	176
	min.	67	23	2	3	2	2	9	
avg.	148	56	4.4	4.5	4.7	5.0	77		

1/ All measurements in mm. Distance between eggs measured from egg-center to egg-center.

Eggs normally are deposited along one side of the selected needle and, at low populations, on only one needle per fascicle (in both shortleaf and Virginia pine).

Extensive egg sampling of shortleaf pine indicates that a female will deposit her complement of eggs on a single twig tip. The average number of egg-infested needles per three-inch twig-tip did not vary from a year of high population to a year of moderate to low populations. The average in both years was 20 needles per tip.

Adult Life Span—In the laboratory, adult life span was found to be inversely influenced by temperature. When temperature varied from 40 to 46°F., adult females lived an average of 11.7 days (range 5-20 days). Life expectancy of the male varied from 6 to 23 days with an average of 12.1 under a similar range in temperature. Adults kept at 65°F. lived 3-4 days, and when the temperature was increased to 75°F., the life span was reduced to two days.

When temperatures in the field are below freezing, the adults become inactive. General adult activity is reduced when the temperature is below 45°F. Adults placed in a freezer at 2°F. for more than a week began to show signs of activity two to four minutes after exposure to room temperature.

Control

NATURAL CONTROL

Sawfly outbreaks have been noted for their sudden increase and just as sudden decline in population densities. Invariably there are numerous natural factors which tend to reduce the numbers of the species. It has been assumed that parasites and predators have been primarily responsible for the sudden decline in populations, but much information is lacking on the influence of these factors on the

population dynamics of sawflies. During the outbreak of *Neodiprion pratti pratti* in Virginia from 1957 to 1962, various natural control factors were studied in detail in order to evaluate the importance of each. Among those studied were insect parasites, insect predators, rodent predators and diseases.

PARASITES

Methods—To determine the impact of insect parasites, a small number of larvae and cocooned prepupae were collected for studies in 1959 and large numbers were collected from 12 to 30 counties from 1960 to 1962. Full-grown larvae were collected from the trees and reared on pine branches in battery jars. When all larvae had changed into the prepupal stage and cocooned, the cocoons were removed and each collection placed in separate emergence containers. Many larvae, especially males, had already left the trees before the samples were taken. Cocoons also were collected from the duff under infested pine stands at intervals of three to four weeks from May until early October during 1960 and 1961, and held for emergence. During 1962 planted cocoons from insectary-reared larvae were used to study prepupal parasites; these were planted in selected counties and replaced at four week intervals.

The following rearing method was designed to simulate outdoor conditions. Two inches of coarse sand was placed in an 8-ounce plastic glass which had five 1/4-inch holes in the bottom. The sand was covered by a layer of pine duff in which the cocoons were placed. The open end of the glass was covered with three thicknesses of cheese cloth. These emergence containers were embedded in trays of moist sand up to the level of the duff in the glasses; holes in the bottom of the glasses permitted the sand and duff within to remain slightly moist.

Sawfly adults and the parasites were removed daily from the emergence glasses and recorded. Solid cocoons remaining in June of the following year were dissected. All identifications were made by specialists at the Insect Identification and Parasite Introduction Research Branch, U. S. Department of Agriculture, National Museum, Washington, D. C.

Egg Parasites—Since eggs of *N. pratti pratti* are present only during the winter and very early spring, they are not usually subject to parasitism. Sawfly eggs were collected each year from 1959 to 1962, but not until the winter of 1961-1962 were any egg parasites noted.

Closterocerus cinctipennis Ash. was reared from collections from several Virginia counties; the degree of parasitism was estimated at less than 1 percent.

Larval Parasites—Among the insects attacking sawflies, larval and prepupal parasites have received the most attention. Four species of parasites were reared from 10,768 sawfly larvae collected from 10

to 15 counties (Table 8) during the 4-year period. A brief biology of each of the species is given below:

Lamachus sp.: Two species belonging to this genus were reared from sawfly larvae, and both have similar life cycles. The adult parasites emerge during the period the sawfly larvae are in the third and fourth instars (Fig. 11), and apparently the small oval eggs are inserted into the host larvae during this time. The parasite larva completes its development as an external parasite after the host cocoon is spun. There is one generation per year, and it is synchronized with the life cycle of *N. pratti pratti*. Parasitism of the host larvae by *Lamachus* spp. was very low during all years, and varied from 0.76 to 4.15% (Table 8).

Exenterus canadensis Prov. is primarily a parasite of mature larvae and prepupae after they leave the trees. Therefore, it will be discussed under the prepupal parasites.

Phorocera hamata A. & W. is a dipterous parasite belonging to the family Tachinidae. The egg is fastened in a fold of the host integument. The larva completes its development after the host cocoon is spun. It was recorded from only two eastern counties and was not important as a parasite of *N. pratti pratti*.

Table 8. Species of Larval Parasites and Percent Parasitism of *Neodiprion pratti pratti* Larvae Collected From Pine Trees From 1959 to 1962.

Species of Parasite	Parasitism			
	1959	1960	1961	1962
—percent—				
HYMENOPTERA				
<i>Lamachus</i> sp. 1	0.65	3.15	0.38	1.45
<i>Lamachus</i> sp. 2	0.42	1.00	0.38	0.31
<i>Exenterus canadensis</i> Prov.	0.06	0.09	0.09	0.07
DIPTERA				
<i>Phorocera hamata</i> A. & W.	0.00	0.13	0.00	0.05
Total Parasitism	1.13	3.37	0.85	1.88
Total Number Larvae (10,768)	276	3,858	5,200	1,434

Prepupal Parasites—As a group parasites of the prepupal stage are most important in reducing the sawfly population. Nine species of prepupal parasites were reared. A total of 12,549 cocoons were collected from an average of 15 counties each year for prepupal parasite studies during the 4-year period (Table 9). A brief biology is given below for each species reared:

Exenterus canadensis Prov. is a yellow-banded Ichneumonid wasp (Fig. 16). The female oviposits principally on prepupae on the ground before they have cocooned. The egg is partially embedded in the dorsal skin of the host larva, and the upper surface of the egg projects through a large oval aperture. The egg hatches after the sawfly prepupa has cocooned, and the parasite larva feeds externally on the host. Individual sawfly larvae may bear as many as six eggs,

but only one parasite larva survives. Approximately 30 percent of the parasites emerge as adults during the same year in which the eggs are deposited; the remainder pass the winter as mature larvae in silken cocoons and emerge as adults the following spring. This emergence is synchronized with the late larval and early prepupal stage of *N. pratti pratti* (Fig. 11).

Endasys subclavatus (Say) belongs to the family Ichneumonidae. The female attacks the sawfly prepupa in its cocoon, and deposits an egg on its body. The parasite larva feeds externally on the host and when mature spins a cocoon within the host cocoon. A life cycle may be completed in approximately six weeks; however, this insect completes only two generations per year, one in early summer and another in the fall. The winter is spent as a full-grown larva in a dark-colored, silken cocoon within the host cocoon. Parasitism by *Endasys* increased each year that studies were made (Table 9). This parasite was reared from prepupae collected from all areas of Virginia but was most numerous in the central counties.

Mastrus sp. is another member of the family Ichneumonidae, and is the most important parasite of cocooned prepupae. The adults are extremely rapid in flight and movement, and remain in the duff on the forest floor with their wings folded flat over their backs. They are negatively phototropic. Observations in the laboratory indicate that very few eggs are matured by an individual female. The female oviposits on the host prepupa within its cocoon, and the parasite feeds externally on the host. The larvae are cannibalistic and only one individual develops within a sawfly cocoon. Approximately three to four weeks are required for a life cycle under field conditions, and there are several generations per year. The majority of the larvae hatching from eggs deposited after mid-summer hibernate as full-grown larvae in small, white, silken cocoons within the host cocoon. They emerge as adults the following spring before new cocoons of *N. pratti pratti* are present (Fig. 11).

Agrothereutes lophyri (Nort.) was not important as a parasite of *N. pratti pratti* from 1959 through 1961, but parasitism by this species increased during 1962. In 1962 it was recorded from five counties and parasitized 10.2% of the cocooned prepupae in Cumberland County.

Dahlbominus fuscipennis (Zett.) is a small chalcid parasite of pine sawfly prepupae within cocoons. It was introduced into the United States from Europe, and has now been colonized in a number of states. It is either primary or hyperparasitic. The female oviposits within the sawfly cocoons, and the parasite larvae feed externally upon the host. Approximately 30 eggs are deposited by an individual female in the host cocoon. As many as 121 adult parasites have been reared from a single cocoon due to oviposition by several females. The life cycle requires approximately three weeks under field conditions and from six to seven generations per year occur under outdoor conditions in south-central Virginia. The winter is

spent as a pupa within the host cocoon. Parasitization by *Dahlbominus* on a statewide basis was quite low but the parasite would probably be effective during epidemic conditions. A comprehensive study of the biology of this parasite under Virginia conditions has been published (5).

Villa sinuosa Wied. is a dipterous parasite belonging to the family Bombyliidae (Fig. 16). Very little is known concerning the life history of this parasite, and no information is available on oviposition. The adults do not seek out sawfly cocoons, and probably deposit eggs or small larvae on the soil and debris. The larva feeds externally on the sawfly prepupa within the host cocoon. The adults are active throughout the summer in all sections of Virginia, and there are probably several overlapping generations per year. They hibernates as large, white, mature larvae in the host cocoon. In this stage they have been refrigerated at 40 to 42° F. for three years and when removed from refrigeration emerged as adults in 31 to 35 days when kept at 75° F.

Table 9. Species of Prepupal Parasites and Percent Parasitism of *Neodiprion pratti pratti* Prepupae in Cocoons From 1959 to 1962.

Species of Parasite	Parasitism			
	1959	1960	1961	1962
	—percent—			
HYMENOPTERA				
<i>Exenterus canadensis</i> Prov.	31.54	21.73	30.74	33.93
<i>Endasys subclavatus</i> (Say)	0.65	2.56	6.14	7.58
<i>Mastrus</i> sp. 1	6.49	14.01	11.70	14.12
<i>Mastrus</i> sp. 2	0.00	0.07	0.06	0.00
<i>Agrothereutes lophyri</i> (Nort.)	0.00	0.04	0.03	2.14
<i>Agrothereutes</i> sp.	0.00	0.04	0.00	0.00
<i>Hemiteles</i> sp.	0.00	0.04	0.00	0.00
<i>Dahlbominus fuscipennis</i> (Zett.)	0.22	1.22	0.79	5.27
DIPTERA				
<i>Villa sinuosa</i> (Wied.)	4.76	8.66	4.93	3.98
Total Parasitism	43.66	48.37	54.39	67.02
Total Number Cocoons (12,549)	660	4,845	3,967	3,077

HYPERPARASITES

Dahlbominus fuscipennis and *Mastrus* sp. were reared from parasite larvae. *Exenterus canadensis* was most commonly attacked (Table 10).

Euceros spp.: The three species of *Euceros* belong to the family Ichneumonidae and apparently have a similar life cycle. The adults begin to emerge when the sawfly larvae are in the second instar. The adult parasites are extremely prolific and produce large numbers of very small eggs. The eggs are deposited on stalks along the pine branches behind the feeding sawfly larvae. The egg hatches into a planidium which attaches itself to the sawfly larva. The planidial

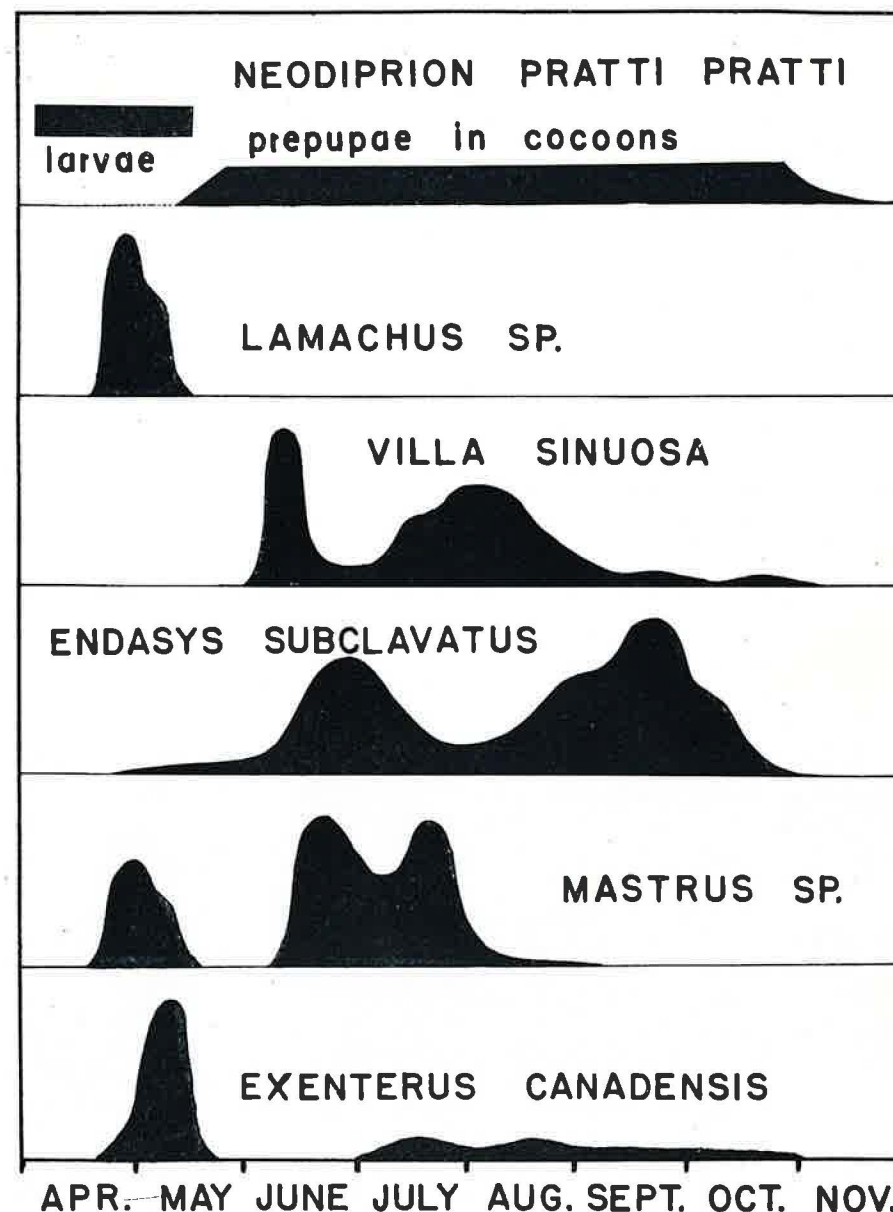


Figure 11. Average time of emergence of larval and prepupal parasites as related to the development of the host, *Neodiprion pratti pratti* (Dyar) from 1959-62.

larva may live on the sawfly prepupa for many months without harm to the prepupa. It continues development only on a parasite larva. Development from planidial stage to adult averaged 35 days for several individuals on *Exenterus* larvae at 75° F.

Table 10. Species of Hyperparasites and Percent Parasitism From 1959 to 1962.

Species of Hyperparasite	Hyperparasitism			
	1959	1960	1961	1962
—percent—				
<i>Euceros</i> sp. 1	0.39	0.84	0.79	1.30
<i>Euceros</i> sp. 2	0.23	0.55	0.22	0.36
<i>Euceros</i> sp. 3	0.68	0.84	1.59	0.87
<i>Mastrus? smithii</i> (Pack.)				0.23
Total Hyperparasitism	1.30	2.23	2.60	2.76
Total Number Cocoons (12,549)	660	4,845	3,967	3,077

PREDATORS

Methods—Observations of larval mortality due to predation by insects were made in infested pine stands throughout the state. All insect predators were identified by the Insect Identification and Parasite Introduction Research Branch, ARS, USDA, Beltsville, Maryland.

Predation of prepupae in cocoons by ants and other arthropods was studied through the use of planted cocoons.

Planted cocoons and cocoons collected from the field were also utilized to evaluate predation by small mammals. All plants and collections were made in stands which had been moderately to heavily



Figure 12. Cocoons were planted both within and just outside the screened enclosures. This was one method used to evaluate small mammals as a factor in control of *N. pratti pratti*.

defoliated. Periodic trapping in the same stands over a period of several years supplemented observations of small mammal activity. Cocoons enclosed in cheese-cloth bags were used on a small scale in 1960. In later years, unbagged cocoons as individuals or as units were utilized. Small mammal exclusion plots enclosing one square yard were fabricated from 1/4-inch hardware cloth. These screen enclosures were partially buried in the ground and used for evaluating small mammal activity during 1961 (Fig. 12). In the insectary, captive mice were caged with buried cocoons to determine their searching ability and feeding habits (Fig. 13).

PREDATORY INSECTS

Larval predators —

Hymenoptera

Formicidae (Ants)

Hemiptera

Reduviidae (Assassin Bugs)

Pseliopus cinctus (Fab.)

Arilus sp.

Pentatomidae (Stink Bugs)

Podisus serieiventris Uhler

Larval predation accounted for only minor losses. All observed instances of larval predation involved only a few individual larvae from a feeding colony.

Prepupal and Pupal Predators —

Hymenoptera

Formicidae

Aphaenogaster rudis Em.

Tapinoma sessile (Say)

Crematogaster lineolata (Say)

Coleoptera

Alleculidae (Comb-clawed beetles)

Lobopoda sp.

Various species of ants are effective predators of cocooned prepupae and sometimes destroy more cocoons than all other predators combined. The above three species (of six species established in the insectary) readily opened cocoons and fed upon the sawfly prepupa. In all probability ants are non-selective in their choice of cocoons, attacking prepupae or parasites alike.

When 600 cocoons were buried in yard-square areas in two locations in Cumberland County in 1960, and 100 removed each month, ants were found to have destroyed 17% of the planted cocoons. A comprehensive study in 1962 designed primarily to study cocoon parasites utilized yard-square trays containing buried cocoons distributed in ten counties. When planted cocoons were removed and replaced with 100 new ones each month, ants were found to have destroyed an average of 13% (range 6% to 26%).

Larvae of *Lobopoda* sp. first became active in the duff during the latter part of August and from this time until sawfly emergence in

November, are capable of penetrating the cocoon and destroying the contents. Activity is resumed in the spring when the larvae probably destroy additional cocoons.

PREDATORY SMALL MAMMALS

Prepupal and Pupal Predators —

Rodentia

Cricetidae

Peromyscus leucopus sub. spp. (White-footed mouse)

Insectivora

Soricidae

Blarina brevicauda (Short-tailed shrew)

The white-footed mouse was consistently encountered in the trapping program which was conducted periodically in the same stands in 1960, 1961 and 1962, and it is considered the primary small mammal predator of cocooned prepupae (Figs. 13, 14). The short-tailed shrew was frequently caught in live traps from many of the same stands but death invariably occurred shortly after capture so that no feeding studies could be conducted. The white-footed mouse was easily maintained for studies of its feeding habits. No other small mammals were found active in defoliated stands.

In August 1960 bagged cocoons were placed in three defoliated stands. This limited test, coupled with concurrent trapping, indicated very little rodent activity in these particular stands.

When individual cocoons were planted at the same density as occurred naturally in the immediate surroundings in a single stand in Cumberland County in 1960, as many as 70% of the cocoons were destroyed by mice in the two months following cocooning.

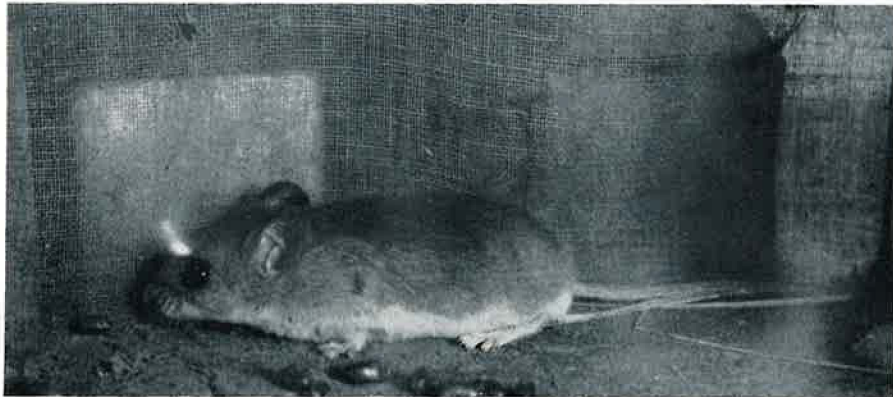


Figure 13. The white-footed mouse was found to be the major small mammal predator of the cocooned sawfly population in Virginia.

In 1961 cocoons were planted in unbagged units of 10, 20 and 40 (five groups in each of eleven defoliated stands). These plants were made during the latter half of May and recovered for evaluation in October. Twenty-one percent of the units (range 0-37%) fell prey to rodents during the cocooning period. The number of cocoons per unit was not a significant factor in evaluating rodent predation in this study.



Figure 14. Underground small mammal tunnel common in sawfly defoliated stands. Considerable small mammal activity also occurred within the duff layer in these stands.

In May 1962, units of two cocoons each were planted in 17 locations in a moderately defoliated stand in Cumberland County. This stand supported a low population of rodents during the early part of the season. By mid-October 355 of the units could be accounted for. Rodents destroyed 11% of the units, 82% had been parasitized or destroyed by other agencies, while the remaining 7% contained living pupae.

Parasite studies involving individual planted cocoons in buried trays (1 tray in each of 9 counties) in 1962 provided additional but not directly comparable data. Between 1% and 64% of the cocoons replanted at monthly intervals in stands where sawflies had been active in the past were destroyed by rodents.

Thirteen one-yard square rodent exclusion plots were established in nine moderately defoliated stands in Prince Edward, King and Queen, Goochland, Fluvanna, Albemarle and Louisa Counties in 1961 (Fig. 12). Cocoons in units of 10 were planted within and just outside the exclusion plot to determine the importance of small mammal predation. Six-hundred-fifty marked cocoons were planted in May in 13 plots and 585 were recovered in October of which 211 were sound. Outside the exclusion plots, 640 were planted; 434 recovered, of which 219 were sound. Rodents were found to have destroyed 25% of the units outside the plots. Approximately the same number (32-34%) remained sound whether rodents were excluded or not.

In laboratory feeding studies, 150 cocoons were buried under a $\frac{3}{4}$ -inch layer of soil, 150 were scattered evenly on the soil surface and covered with a thin layer of duff and an additional 100 were scattered through the layer of pine needles that covered the tray. A single white-footed mouse placed in the enclosure and provided with an alternate food of dog biscuits, located 100% of the cocoons in the pine needles, 92% of the cocoons in the duff and 52% of the cocoons in the soil in two days. Cocoons thus found were opened in a variety of ways; most often a single hole was chewed near the middle of the cocoon (Fig. 15).

When caged mice were offered an unlimited supply of exposed cocoons they consumed more than 300 per day per mouse. In addition, many cocoons were opened and the sawfly prepupae removed but not eaten. When cocoons were so abundant the head capsule and the thoracic regions of the prepupae were rejected. Under normal conditions the head capsule is the only portion not consumed.

Stomach contents from laboratory-reared and field-collected mice were examined. It was extremely difficult to identify portions of recently consumed sawfly prepupae by this method.

OTHER PREDATORS

Prepupal and Pupal Predators

Julida (Millipede)

Parajulidae

Uroblaniulus canadensis (Newport)^{1/}

Millipedes have been observed in the laboratory and under field conditions to penetrate the prepupal cocoon and consume the prepupa (Fig. 15). They were found to be only a minor predator of cocoons in these studies.

^{1/} Identification by Richard L. Hoffman, Radford College, Radford, Virginia.

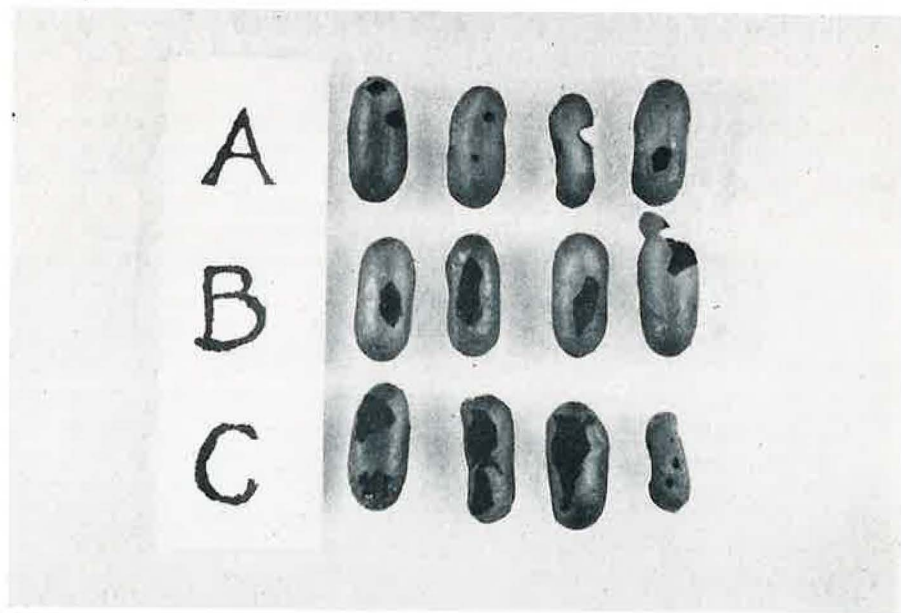


Figure 15. Characteristic openings made in sawfly cocoons by:

- A. Millipedes
- B. Mice
- C. Ants

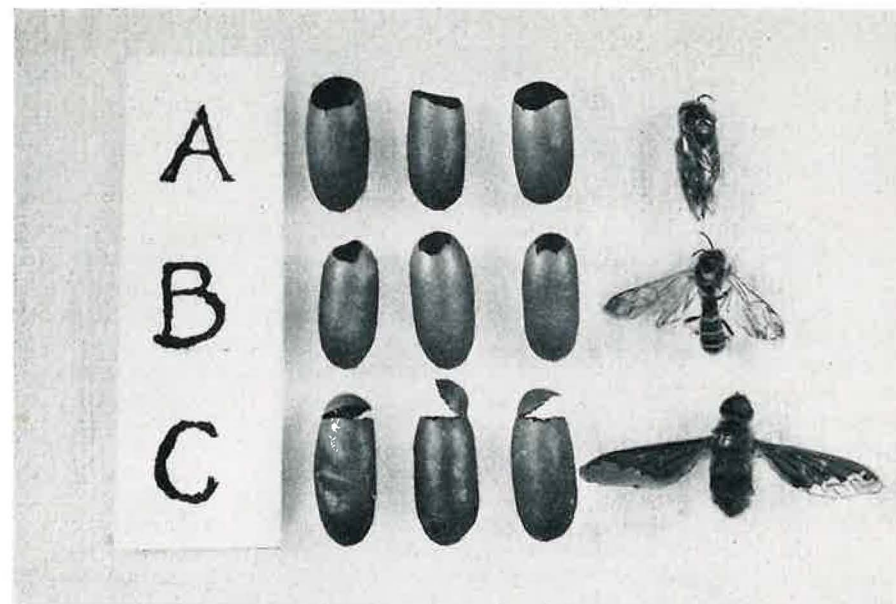


Figure 16. Typical emergence holes made from cocoons of *N. pratti pratti* by:

- A. *N. pratti pratti* female
- B. *Exenterus canadensis*
- C. *Villa sinuosa*

DISEASES

Infectious agents such as the polyhedral virus, bacteria or fungi were not primary controlling factors in the outbreak of *N. pratti pratti* in Virginia during the period 1957-1963. Although a constant surveillance was maintained for diseased larvae and prepupae throughout this period in order to test all disease agents for their applicability in control in the field, it was not until 1959 that any larval mortality due to disease was noted. Thereafter, occasional larvae killed mainly by virus—but probably also by bacterial infection—were a more common sight, particularly during 1961 and 1962 in Amelia, Buckingham and Cumberland Counties.

The greatest mortality in the larval stage occurs early in the first instar due mainly to the failure of the larvae to become established and begin feeding. The young larvae often fall from the foliage during this period. Low humidity was found to be the most important reason for lack of successful establishment of newly hatched larvae in the lab.

During the period 1960-1963 individual groups of sawfly eggs were tagged, counted and larval development was followed through weekly observations. The average loss due to all agencies through the larval period was found to be 24%. In 1961, because of protracted cool, wet weather during the early period of larval development, mortality increased (Table 11).

Table 11. Larval Mortality.

Area	Year	No. of Colonies	No. of 1st Instar Larvae	No. of Mature Larvae	Loss
Louisa County	1960	8	309	247	20%
Louisa County	1961	13	442	303	32%
Louisa County	1962	18	433	329	24%
Louisa County	1963	10	399	337	16%

The main disease responsible for killing prepupae in cocoons was found to be caused by the fungus *Beauveria bassiana* (Bals.) Vuill.^{1/} This fungus mummified the prepupae in its natural form. Infected prepupae could be identified by rolling the unopened cocoon between the fingers to detect the hardened insect inside. Occasional cocoons were also found which contained dark, liquified remains of the prepupae. The figures in Table 13 reflect these losses. Virus infection was never found to be the major cause of mortality in prepupae except in the experimental spray area.

In 1960, 1961 and 1962 late instar larvae and prepupae in cocoons were collected periodically throughout the summer from a dozen or more locations during the insect parasite study. Based on annual collections of 3000-4500 cocoons, prepupal mortality was found to be 33% in 1960, 18% in 1961 and 30% in 1962. Prepupal mortality in cocoons spun by field-collected larvae was comparable when this data was taken in 1960 and 1962. This mortality was somewhat higher than that found in other cocoon collections (Table 13).

Annual attempts at mass-rearing of late-instar larvae in galvanized tubs in the insectary resulted in larval mortality as high as 30 percent in occasional tubs. Virus polyhedra were present in a large proportion of the dead larvae. This fact supports the widely held opinion that viruses in many sawflies are latent forces which become important agents of control during periods of high populations and/or during periods of larval stress induced by starvation or abnormal environmental conditions. A pattern of increasing larval mortality was experienced when successive colonies of larvae were reared in the lab from eggs collected at monthly intervals during the winter. Mortality due to virus infection increased with each successive overlapping larval period.

See "Applied Control" for further discussion of the polyhedral virus as a control agent in the field.

1/ Identified by Mrs. Marie L. Lack, ARS, USDA, Beltsville, Maryland.

DISCUSSION

It will be noted in Table 9 that parasitism by prepupal parasites varies considerably from 1959 to 1962. This variation, however, is partially due to the method used in determining the percentage. During 1959, the prepupal parasite studies were not begun until July 1, and thus one or more generations of the multi-brooded species

were missed before collections were initiated. All data on parasitism for the years 1959 through 1961 are based on the collection of sound cocoons at approximately monthly intervals from a number of counties. A small but undetermined number of the parasites emerged between cocoon collections, and the records do not include this emergence. During 1962 planted cocoons were used in all prepupal parasite studies and proved to be the most reliable method of determining parasitism by the multi-brooded species.

Available data indicate that no single factor of natural control was responsible for the decline of the recent outbreak of *N. pratti pratti*. The reduction in population densities has been the result of a number of contributing factors, the more important of which were insect parasites, insect and rodent predators, diseases, and apparent loss of vigor by the adult sawflies.

Data obtained during the study shows that 23% of the larvae died before reaching maturity, due to unfavorable climatic conditions and to various diseases. An additional 2% were parasitized by larval parasites. Predatory insects were occasionally observed feeding on the larvae but were of minor importance.

Parasitic and predaceous enemies of the prepupae were most important in reducing the sawfly population. Predatory mammals destroyed approximately 21% of the prepupae, predatory insects 17%. Of those remaining, parasitic insects destroyed 59%, and diseases 27% (Table 12).

From these data it is calculated that 88% of the sawfly population was destroyed by all natural control factors (Fig. 17), and these factors may have been responsible for the decline of the sawfly epidemic during 1961 and 1962. However, calculation from biological data (Table 12) indicates that destruction of at least 95% is necessary to reduce the sawfly population. These observations lead to the belief that other factors, including loss of vigor, contributed to the decline of the sawfly population.

During the years of high sawfly populations in the field, the adults mated soon after emergence in the insectary, and the females oviposited 88.3% of the eggs present in the ovaries. During the years of sawfly decline (1961-1962) only rarely was copulation observed.

Table 12. Data on the Biology and the Natural Control Factors of *N. pratti pratti*, 1960 to 1962.

Number eggs matured per female	69.0
Percent females ovipositing in insectary	61.5
Percent of eggs oviposited by mated females	88.3
Percent of eggs oviposited by unmated females	19.7
Percent eggs hatching	85.0
Percent larval mortality	23.2
Percent larvae parasitized	1.9
Percent larvae producing females	57.5
Percent prepupae in cocoons destroyed by mammals	21.2

Percent prepupae in cocoons destroyed by insect predators .17.0
 OF THOSE REMAINING
 Percent prepupae in cocoons destroyed by insect parasites .58.9
 Percent prepupae in cocoons destroyed by disease27.0

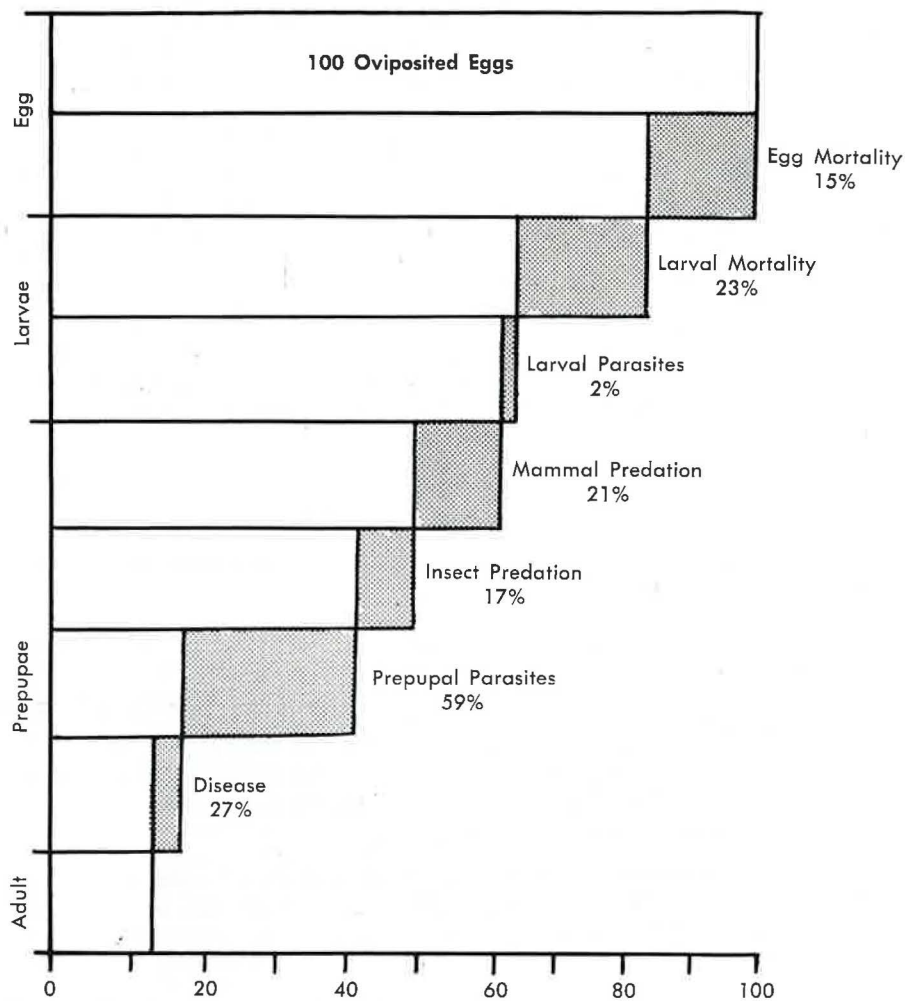


Figure 17. Average annual destruction of *N. pratti pratti* by natural control factors, 1960-1962.

SUMMARY

Parasites—Seventeen species of primary and hyperparasites were reared from the various life stages of *N. pratti pratti* from 1959-1962. Prepupal parasites were most important. Four species, *Exenterus canadensis*, *Mastrus* sp., *Endasys subclavatus* and *Villa sinuosa*, accounted for approximately 90% of the total parasitism. Hyperparasitism was not important during the period of the study.
Predators—The white-footed mouse was found to be the most im-

portant small mammal predator of prepupae in cocoons during periods of high sawfly populations when they destroyed as many as 70% of the cocooned population. Rodent activity was observed to be highest during the second successive year of severe defoliation. During periods of moderate to low sawfly populations, rodent activity varied widely between individual stands.

Various species of ants are also effective predators of cocooned prepupae, and sometimes destroy more cocoons than all other predators combined. They destroyed an average of 17 percent of the cocoons each year.

It was difficult to determine all agents involved in cocoon destruction by using characteristic openings or exit holes (Figs. 15, 16).

Larval predation by ants and various other insects is a minor factor. Birds were not observed to feed on any stages of the sawfly.

Infectious agents such as bacteria, fungi or viruses, were not found to be a primary controlling factor during the outbreak of *N. pratti pratti* in Virginia during the period 1957-1963.

APPLIED CONTROL

INTRODUCTION OF PARASITES

The imported European cocoon parasite, *Dahlbominus fuscipennis* (Zett.) was released in large numbers in the 1930's in eastern Canada and in New England against the European spruce sawfly (Fig. 18). The most recent large scale releases were made in New Jersey from 1957-1959 against *N. sertifer* and several native sawflies.

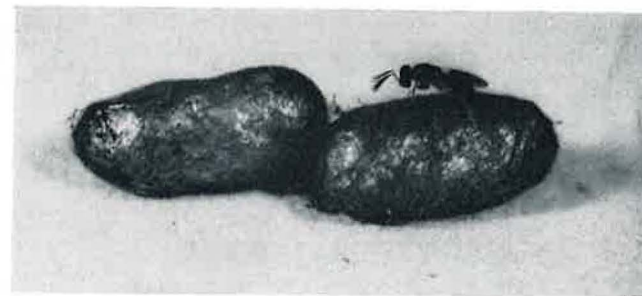


Figure 18. *Dahlbominus fuscipennis* (Zett.) was introduced into Virginia counties where it had not already spread from releases in other states.

Because *N. pratti pratti* remains cocooned during the summer months, the introduction of *Dahlbominus* into the complex of native parasites appeared practical in light of the experience of earlier investigators. Since under normal moisture conditions the majority of cocoons of *N. pratti pratti* are spun beneath the duff at ground level, and sometimes in the soil itself, the effectiveness of this parasite—as well as the native cocoon parasites—was known to be limited.

The New Jersey Department of Agriculture kindly supplied information and equipment to begin the rearing program in Virginia. The general rearing procedures followed are described by Miller (14). A relative humidity range of 70-80% was maintained; temperature ranged between 65-75° F. Cocoons of *N. pratti pratti* (field-collected as larvae and held for cocooning) used for parasite rearing were pre-treated for two minutes at 113° F. in a 5% glycerine-water bath. Treatment at higher temperatures apparently rendered the prepupae less acceptable to the parasites. Glycerine softened the cocoons and increased parasitism, which averaged 35% for all rearing in 1961. Adults were not fed in the rearing cages.

Cocoon sampling during 1959 revealed that *Dahlbominus* had already become established in Spotsylvania, Fauquier, Fluvanna, Louisa and Goochland Counties, apparently moving southward from releases made in other states. By 1960 it was found to be well established in Cumberland, Prince Edward, Buckingham, Hanover and Powhatan Counties. All releases in Virginia were made in counties where no natural establishment had been confirmed.

In 1959 a total of 23,000 parasites were released in seven Virginia counties. One hundred seventy-nine thousand were released in 12 counties during 1960, and 750,000 were released in 1961 throughout 21 counties, mainly along the eastern edge of the infestation. An estimated 1,000 parasites were released (as pupae) in selected infested stands. By the time the release program was discontinued, following the 1961 season, multiple introduction had been made in all counties where the sawfly had caused moderate to heavy defoliation.

In 1961, *Dahlbominus* was recovered from cocoon plants made in Westmoreland and King George Counties, although it was not known if the presence there resulted from "natural" spread or from releases made in 1960. In September 1962, attempts to trap adults in five counties where releases had been made in 1960 and 1961 were unsuccessful.

Bobb (5) studied this parasite in the course of his investigation of native parasites of *N. pratti pratti*, and found that it parasitized 5.3% of his planted cocoons in 1962 (Table 9).

POLYHEDRAL VIRUS

The field application of a virus to control the European pine sawfly *N. sertifer* was first reported by Bird (4). A polyhedral virus recovered from the native population of *N. pratti pratti* in the Beltsville, Maryland area was successfully applied against *N. pratti pratti* in small scale tests on the ground by Dutky *et al* in 1955 (U.S.D.A. News Release dated 17 February 1956) and by McIntyre and Dutky (12) by aerial applications.

A supply of this virus (Accession No. DD-635) was obtained from Dutky in 1959 and was applied in April 1959 by air at the rate of 5 billion polyhedra per acre (in 2 gallons of water per acre) to a ten-acre tract in Louisa County heavily infested with *N. pratti*

pratti. Larvae had hatched 10 days earlier and were in the late second instar. Larval mortality became evident in 14 days (Fig. 19). The spray eventually killed an estimated 75% of the larvae before cocooning. No carry-over of the disease in the sprayed area was apparent the following year until the prepupae spun their cocoons. Similar observations were made by McIntyre and Dutky (12). The unusually high mortality of cocooning prepupae collected from drop-cloths at that time was found to be the result of infection by the polyhedral virus. However, overall reduction in the population at the time of cocooning in the sprayed area due to virus infection was estimated to be 10% or less the second year. The larval population for the two years following the spraying did not differ noticeably from that found in nearby stands (a sharp drop in population occurred throughout the county the year following application of the virus in the test stand).

Diseased larvae were collected from the virus spray area to insure a future supply. This supply provided a source of the virus for application during early and late larval development periods (at the same rate as 1959) to infested roadside pines in Prince Edward County in 1960. A 200-gallon hydraulic sprayer and a back-pack mist blower were utilized for application. Sawfly eggs were collected from these sprayed roadside areas the following year. None showed unusually low hatching incidence or virus infection in the young larvae. Similar observations were made of eggs laid by caged adults developing from larvae sprayed with the virus which failed to succumb to disease. No transmission of the virus through the egg to cause mortality in young larvae could be demonstrated in these limited field experiments and observations.

In 1961 polyhedral bodies were confirmed in recently hatched first instar larvae collected from the field in Dinwiddie County. Polyhedra were about 1/2 the size of those characterizing the Beltsville virus. First propagated in the lab by spraying captive larval colonies, it was applied in the field in early May to compare its effectiveness with the Beltsville virus. Both appeared equally effective in field use. Larvae sprayed with the Dinwiddie virus showed polyhedral bodies similar in size to those characterizing the Beltsville virus.

Virus suspensions from *N. sertifer* provided by the Canadian Department of Agriculture, Central States Forest Experiment Station (U.S.F.S.), and the New Jersey Department of Agriculture were applied in 1960 to *N. pratti pratti* larvae 20 days before cocooning. A suspension of virus from *N. lecontei* from Canada was also used. None of these virus suspensions had a noticeable effect on the larvae.

BACILLUS THURINGIENSIS

At the same time the polyhedral virus from Beltsville was applied by air to the ten-acre block of pine in Louisa County, a formulation of *B. thuringiensis* provided by Merck and Company, Inc. was applied by air to a heavily infested stand of 10 acres in Cumberland

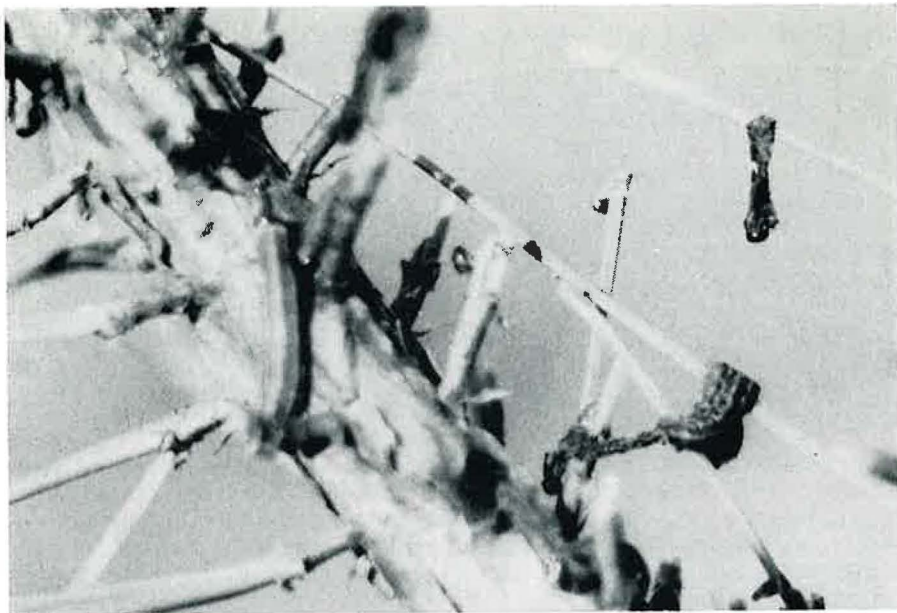


Figure 19. Larvae infested as the result of a heavy application of a polyhedral virus.

County. This material was formulated as a wettable power containing 70 billion viable spores per gram and was applied at the rate of 0.7 lbs. of the wettable powder per acre. No larval mortality resulted from this application. When a spray containing five ounces of the wettable power per gallon was applied to nearly full-grown larvae in May 1959, mortality resulted in 4 days; lesser amounts were ineffective.

In 1960 Stauffer Chemical Company's formulation of *B. thuringiensis* (Thuricide 30B WP) was tested at the rate of 2-4 heaping tablespoons per gallon of water applied to individual colonies by hand. No control resulted at this rate of application.

OTHER INSECTICIDES

It is estimated that less than 400 acres of private or company-owned pine woodland in Virginia was sprayed for control of the pine sawfly during the outbreak period. Insecticidal control on forest land was not encouraged by the Division during the epidemic since little mortality was expected and reinfestation was likely the next year unless large blocks were protected.

McIntyre (10) obtained satisfactory control of *N. pratti pratti* in Maryland in 1958 using an aerial application of DDT at the rate of one pound per acre.

Six and one-half pounds of 20% granular aldrin insecticide was applied to 1500 sq. ft. of the forest floor at the time of cocooning

on May 6, 1959. Sampling of the cocooned population on August 7, 1959 showed 56 sound cocoons present in 7 square feet, of which 50% were parasitized, 10% fungoused. The treatment was assumed to have given little or no control.

Survey Methods

WINTER EGG SURVEYS TO PREDICT DEFOLIATION

Egg surveys have been useful in predicting defoliation caused by a number of forest insects including the forest tent caterpillar, elm spanworm and various sawflies. To develop a sampling technique for *N. pratti pratti* in Virginia, 322 pine stands were selected randomly in nine counties in the central and southern Piedmont early in 1959. Ten interior shortleaf or Virginia pines, one-half chain apart, were selected to represent each stand. Two 3-inch twig tips per tree were obtained from the lower or middle crown by use of a shotgun. Prediction of defoliation was based on the number of egg-infested trees per 10-tree sample:

- 5-10 trees infested with eggs: HEAVY defoliation expected (over 50% foliage removed)
- 2-4 trees infested with eggs: MODERATE (20-50% defoliation)
- 0-1 trees infested with eggs: LIGHT TO NEGLIGIBLE (0-20% defoliation)

This type of sampling was found to give a $\pm 20\%$ accuracy in predicting degree of defoliation when moderate to high sawfly populations occurred and proved suitable for county-sized survey units. This same survey method was utilized in 1960, but only 150 stands were sampled.

Meanwhile, a sequential sampling plan for shortleaf pine based on a 15-inch twig sample was developed by the Southeastern Forest Experiment Station (16). Concurrently, McIntyre (then of Northeastern Forest Experiment Station) developed a sequential plan for Virginia pine in the Beltsville, Maryland area. Neither of the sequential survey methods proved practical as sawfly populations diminished, so the plot survey method was used again in 1960 and 1961 while other roadside survey techniques were being developed and tested.

In 1962, a 1,000-mile roadside survey using these new techniques, which involved sampling at 10-mile intervals, was instituted. A single 15-inch twig was clipped from the exposed middle or lower crown of five Virginia or shortleaf pines on the southern or western edge of a stand. Prediction of defoliation was then based upon:

No. Samples with Eggs	Avg. No. Egg-Infested Needles/infested twig	Predicted Defoliation
4 - 5	over 50	HEAVY (Over 50% of foliage removed)
	under 50	LIGHT TO MODERATE
2 - 3	over 50	MODERATE (20-50% of foliage removed)
	under 50	LIGHT
0 - 1	over 50	LIGHT (10-20% of foliage removed)
	under 50	NEGLIGIBLE (Less than 10% of foliage removed)

An extensive comparison of this sampling method with the 10-tree sample method showed improved accuracy and a considerable saving in survey time. This new method was utilized in January 1962, and again in 1963. The accuracy of the prediction based on these various survey methods was checked in 1959, 1960, 1961 and 1962 by cooperative aerial defoliation surveys (11, 13, 8, 7).

COCOON SAMPLING

Cocoon sampling has been suggested as a basis for predicting defoliation by coniferous sawflies in the United States and Canada. To investigate this sampling technique in Virginia and to determine any changes in the parasite populations from year to year, cocoons were collected from litter and soil beneath defoliated pines in 1959, 1960 and 1961. Although there was a considerable range between samples from individual stands and within the same stand, there was little change from year to year in the average number of solid cocoons found containing immature insect parasites (Table 13). This figure ranged from 50 to 59% and approximated that found in the more intensive sampling for the parasite study (Table 9).

Table 13. Area Sampling for Sawfly Cocoons.

Location (Co.)	Date of Sampling	No. of ^{1/} Sound Cocoons	Parasitized Cocoons (%)	Non-parasitized Cocoons (%)	
				Dead Pre-pupae	Live Pre-pupae
Fluvanna, Louisa, Cumberland, Mecklenburg	July- Aug. 1959	620 ^{2/}	47 (20-90)	—	—
				Cumberland, Buckingham	July 1959
Cumberland	Aug. 1959	118 ^{4/}	34	46	20

1/ Based on square yard counts in 1960, 1961; on smaller and variable-sized units earlier.

2/ Based on a 10-cocoon sample from collections made in 62 stands.

3/ A composite sample from ten stands.

4/ Reared by B. D. Burks, U.S.D.A., Washington, D. C.

Table Con't.

Location (Co.)	Date of Sampling	No. of ^{1/} Sound Cocoons	Parasitized Cocoons (%)	Non-parasitized Cocoons (%)	
				Dead Pre-pupae	Live Pre-pupae
Fluvanna	July 1959	100	74	2	24
Fluvanna	Aug. 1959	112 ^{2/}	44	29	27
Louisa	Aug. 1959	26	54	7	39
Louisa	Aug. 1959	56	50	16	40
Louisa	Aug. 1959	114 ^{2/}	60	15	25
Mecklenburg	Aug. 1959	90 ^{2/}	50	29	21

Avg. (1959): 50% of sound cocoons parasitized.

Louisa ^{3/}	Dec. 1959	138	70	15	15
Cumberland	Sept. 1960	37	76	24	0
Cumberland	Sept. 1960	50	70	14	16
Goochland	Sept. 1960	39	38	19	43
Louisa	Sept. 1960	45	51	7	42

Avg. (1960): 59% parasitized.

Prince Edward, Louisa, Gooch- land, New Kent, King William	Sept. 1961	191 ^{4/}	53 (20-86)	7	40
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Avg. (1961): 53% parasitized.

When cocoons containing prepupae were planted in 1961 in units of 10, 20 and 40—primarily to assess small mammal predation—18% of the sound cocoons remaining just prior to emergence of the adult sawfly contained immature parasites. When units of two cocoons were used in 1962, 33% of the solid cocoons remaining were found to be parasitized. Since these planted cocoons contained prepupae which were reared in the insectary, the incidence of larval and some prepupal parasites is not reflected in these percentages.

Since the average percentage of sound cocoons containing immature parasites did not fluctuate markedly from year to year, this figure did not appear to be a suitable index of future changes in sawfly populations. Unfortunately, data for the critical year of probable parasite build-up (1958) is lacking. A comparison of the number of sound cocoons containing healthy prepupae at the beginning and at the end of the cocooning period may serve as a guide to the future population trend, however (Table 14).

1/ Based on square yard counts in 1960, 1961; on smaller and variable-sized units earlier.

2/ Reared by B. D. Burks, U.S.D.A., Washington, D. C.

3/ Collected from 4 separate stands after adult emergence.

4/ Total of 11 random square yard counts in the counties indicated.

Table 14. Periodic Resampling of Sawfly Cocoons Under the Same Trees—1961.

Location	% Defoliated 1961	Sampling Date	Current Year's Cocoons (per sq. yd.)		
			Total	% Sound ^{1/}	% Destroyed
West Point, Va. Stand A, Tree 1	30%	May 19	44	100	—
		June 1	74	98	—
		August 14	109	9	—
		October 9	56	25	89
West Point, Va. Stand A, Tree 2	95%	May 19	254	98	—
		June 1	81	100	—
		August 14	199	7	—
		October 9	192	25	89
West Point, Va. Stand B, Tree 1	35%	May 22	96	98	—
		June 1	76	98	—
		August 1	138	28	—
		October 9	123	21	88
Farmville, Va. Stand A, Tree 1	30%	May 19	87	98	—
		August 14	84	29	—
		October 9	65	18	91
Farmville, Va. Stand B, Tree 1	15%	May 22	27	85	—
		June 2	67	96	—
		August 1	159	9	—
		October 9	94	4	98

In the study of parasitic insects, 52 collections were made at monthly intervals from May to September in 1960 in 26 counties in Virginia. Total cocoons numbered 5,087. Similarly, in 1961 forty-six collections in 19 counties totaling 3,149 cocoons were made. Examination of the percentage of sound cocoons parasitized indicates that June would be the best month in Virginia to conduct cocoon sampling to obtain the most reliable estimate of aggregate parasitism (Table 15).

Table 15. Percent of Sound Cocoons of *N. pratti pratti* Containing Immature Parasitic Insects from Periodic Collections Made in 1960 and 1961.

Year	Month	No. of Collections	Per-cent Parasitism	Year	Month	No. of Collections	Per-cent Parasitism
1960	May	10	37.4	1961	May	8	60.3
	June	10	66.7		June	23	61.3
	July	20	59.2		July	9	45.5
	Aug.	10	49.3		Aug.	2	41.9
	Sept.	2	27.3		Sept.	4	56.1
Aggregate Total		52	52.0	Aggregate Total		46	56.6

1/ Since combination of prepupal mortality and parasitization was found to be 55% (based on cocoon plants and cocoon sampling in these same stands), 45% of the solid cocoons remaining 10/9/61 would contain prepupae.

Radial Growth and Volume Loss

Seven fully-stocked mixed stands of shortleaf pine and Virginia pine located in Piedmont Virginia were selected for study in May 1959 to determine growth losses due to sawfly defoliation. These stands were subjected to severe defoliation by *Neodiprion pratti pratti* in 1958 and 1959. Six of the stands were located in Louisa County and one in Cumberland County. The average defoliation in all stands in both counties as determined by intensive ground and aerial surveys was 5% in 1957, 50% in 1958, 60% in 1959, 10% in 1960 and 3% in 1961 and 1962. Average defoliation for all study trees was approximately equal to these county-wide averages. Individually, study trees varied in defoliation from 0 to 100%. Ten additional open-grown shortleaf pines in Stand 9 are considered separately, since they first suffered severe defoliation in 1957—a year earlier than the other stands.

All trees selected in each stand were located in and immediately surrounding a 1/5-acre plot which was used to determine stand density, average height and average diameter breast high. Percent of total needles consumed was recorded for each individual

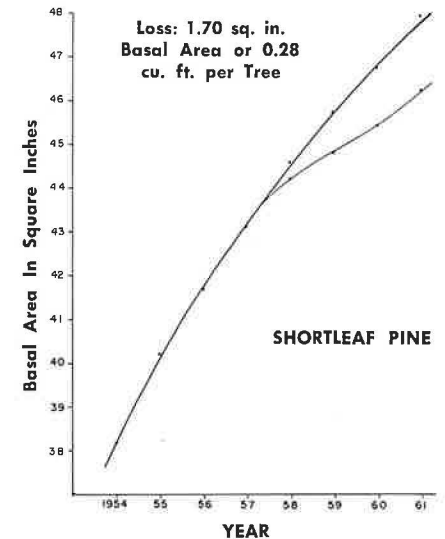


Figure 20. Basal area of the average shortleaf pine suffering less than 20% defoliation in 1958 and 1959 (upper curve), compared with basal area of the average shortleaf pine suffering 60% defoliation in those years.

Table 16. Radial Growth (mm) of Shortleaf Pines in Stands Defoliated 50% or more in 1957, 1958, and 1959.

Stand	No. Trees	1955	1956	1957	1958	1959	1960	1961	1962
1	33	85.14	67.57	61.82	47.21	26.25	20.63	20.88	—
3	34	59.01	52.93	45.67	37.65	21.94	19.36	27.82	—
4	36	60.93	53.07	43.20	39.57	25.40	19.99	25.33	—
5	19	22.98	25.70	24.89	19.21	10.68	11.44	19.65	—
6	8	13.49	12.08	12.13	7.02	3.82	4.40	7.04	—
7	36	91.86	78.63	64.75	44.83	23.69	24.61	34.18	—
8	31	57.90	53.58	48.56	37.87	24.17	26.57	28.38	—
Totals	197	391.31	343.56	301.02	233.36	135.95	127.00	163.28	—
Averages:		1.98	1.74	1.53	1.18	0.69	0.64	0.83	—
Defoliation:		—	—	5%	60%	62%	9%	3%	—
Stand	No. Trees	1955	1956	1957	1958	1959	1960	1961	1962
9	9	39.0	30.7	14.7	8.4	8.1	16.4	27.5	19.7
Averages:		4.3	3.4	1.6	0.9	0.9	1.8	3.1	2.0
Defoliation:		—	10%	95%	75%	51%	26%	2%	2%

tree shortly after larval activity ceased. Ten percent of the selected shortleaf pines were in the intermediate crown class; the remainder were classed as dominants and co-dominants. All Virginia pines were either dominant or co-dominant.

Site indices ranged from 56 to 67 for shortleaf pine, with an average of 61 for all seven stands. The average site index for all shortleaf pine stands in Piedmont Virginia is 60. The site index for Virginia pine growing in the same stands averaged 63.

METHODS—In December 1961, sample cores were extracted with an increment borer (at breast height) from the N, E, S, and W sides of all selected trees in Stand 4. Although there was considerable variation for a given year in the radial increment on the four sides, an analysis indicated that the average of two measurements (from the northern and western side of the tree) would be suitable. Annual increment was measured to 1/20mm immediately after collection. All measurements were made at 15x with a micrometer disc mounted in the eyepiece of a binocular microscope.

A total of 197 shortleaf and 23 Virginia pines from the seven stands comprised the sample (Tables 16, 17). Cores from an additional 20 shortleaf and 26 Virginia pines from five nearby stands suffering less than 20% defoliation were selected for comparison (Tables 18, 19). Basal area was chosen as basis for growth comparison. The basal area of the average tree from the seven stands suffering severe defoliation was compared by species to the average tree only lightly

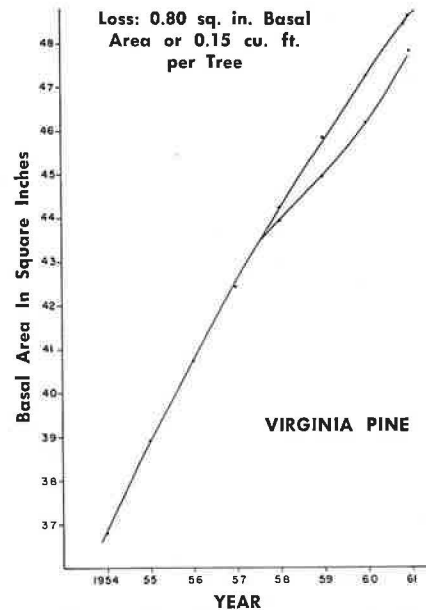


Figure 21. Basal area of the average Virginia pine suffering less than 20% defoliation in 1958 and 1959 (upper curve) compared with the basal area of the average Virginia pine suffering 55% defoliation in those years.

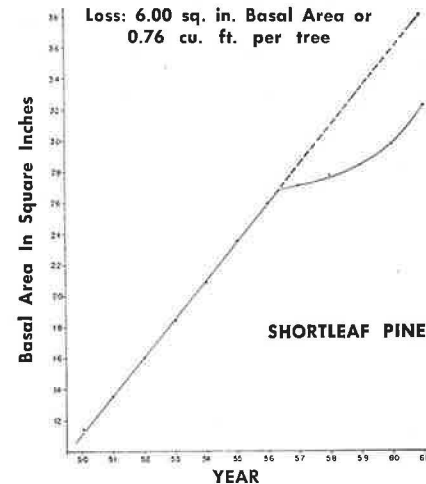


Figure 22. Basal area of the average young open-grown shortleaf pine (Stand 9), severely defoliated 1957-1959, compared with the projected or theoretical basal area of the average undefoliated tree (broken line).

Table 17. Radial Growth (mm) of Virginia Pines in Stands Defoliated 50% or more in 1958 and 1959.

Plot	Trees	1955	1956	1957	1958	1959	1960	1961
1	1	3.25	2.10	2.07	2.05	1.23	1.75	1.80
2	3	12.12	10.82	8.05	6.85	3.72	4.17	8.52
3	3	8.04	5.74	4.04	4.79	3.94	3.59	4.95
4	1	3.35	2.95	2.90	3.40	2.65	2.95	4.15
5	4	8.02	8.09	6.72	7.07	4.37	4.67	7.00
6	11	21.97	23.04	17.69	19.08	11.16	11.99	17.16
Totals	23	56.75	52.74	41.47	43.24	27.07	29.12	43.58
Averages		2.47	2.29	1.80	1.88	1.18	1.27	1.89
Defoliation:				5%	55%	56%	18%	3%

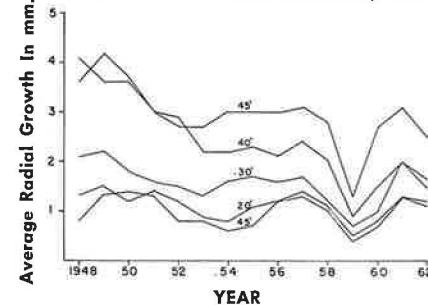
Table 18. Radial Growth (mm) of Shortleaf Pines in Stands Defoliated 20% or Less in 1958 and 1959.

Stand	No. Trees	1955	1956	1957	1958	1959	1960	1961
428	1	2.23	1.63	1.68	1.40	0.95	0.75	0.55
268	8	21.40	15.55	5.27	15.50	11.57	9.35	13.10
486	2	2.02	2.10	2.12	1.55	1.37	1.02	0.89
238	4	7.47	6.64	4.24	4.25	3.72	2.97	3.10
11	5	11.37	8.62	7.97	8.85	7.62	5.27	8.38
Totals	20	44.49	34.54	31.28	31.65	25.23	19.36	26.02
Averages:		2.22	1.73	1.56	1.58	1.26	0.97	1.30

Table 19. Radial Growth (mm) of Virginia Pines in Stands Defoliated 20% or Less in 1958 and 1959.

Plot	No. Trees	1955	1956	1957	1958	1959	1960	1961
428	12	25.07	19.52	16.42	26.02	17.32	16.12	17.35
268	2	5.93	5.00	4.33	5.03	4.43	3.75	4.28
486	6	14.98	14.00	12.25	12.35	10.15	8.05	8.30
238	6	17.61	14.64	9.39	13.71	13.13	9.64	10.01
Totals	26	63.59	53.16	42.39	57.11	45.03	37.56	39.94
Averages:		2.45	2.04	1.63	2.20	1.73	1.44	1.54

Plot 5, Tree No. 17 30% Defoliated, 1959



Plot 5, Tree No. 2 100% Defoliated, 1959

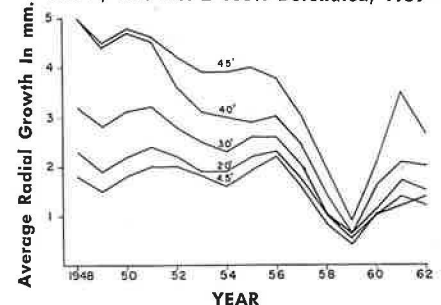


Figure 23. Annual radial growth at the five sampling points on the bole for two of the four dominant shortleaf pines cut and sectioned during the winter of 1963.

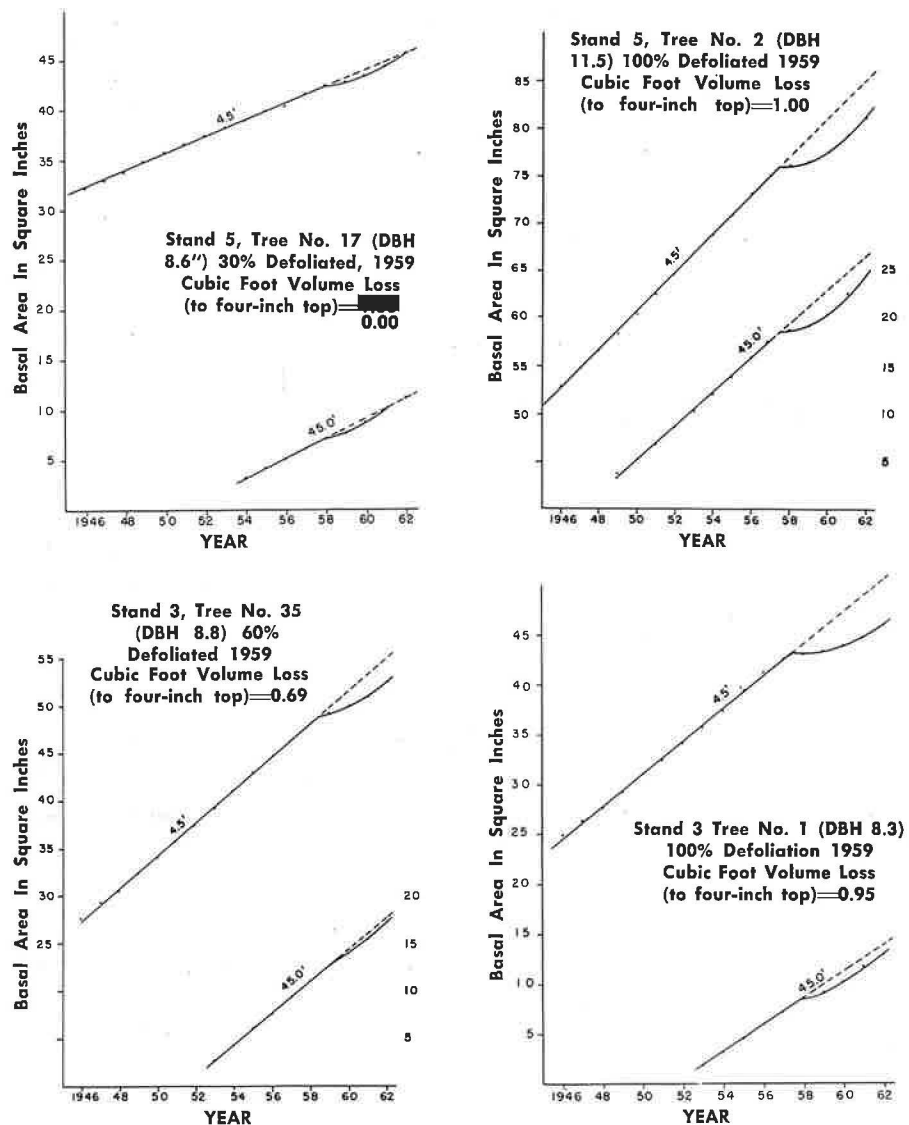


Figure 24. Basal area curves from sections taken at 4.5' and 45.0' for the four dominant shortleaf pines cut and sectioned during the winter of 1963. Actual basal area—reflecting defoliation—is compared with theoretical basal area of an undefoliated tree (broken line).

attacked (Fig. 20, 21). Data from the young open-grown shortleaf pine in Stand 9 which suffered heavy defoliation for the period 1957-1959 is shown in Figure 22. Projected basal area increase served as a basis for comparison in this case.

Four dominant shortleaf pines (two in Stand 3, and two in Stand 5) were selected in January 1963 to determine (a) when and

where growth loss is reflected, (b) if this growth loss is expressed proportionately throughout the stem, and (c) if growth loss is correlated to the degree of defoliation. Discs from heights of 4.5 feet, 20 feet, 30 feet, 40 feet, and 45 feet were removed from each tree. In all cases the disc taken at 45 feet was the limit of merchantable height (4 inches) and fell in the lower portion of the crown. Annual radial growth of each disc (average of the four measurements) was recorded and plotted for each sampled tree. Two of the curves are shown in Figure 23. The growth pattern followed that described for other conifers (6, 15, 19). In addition, basal area at 4.5 feet and 45 feet was compared with the projected basal area increase at these heights (Fig. 24).

DISCUSSION

It is obvious from Figure 23 that growth loss is expressed at the same time in all parts of the tree and is proportional throughout the stem.

Since basal area increase for shortleaf pine bears a straight line relationship on site 60 up to age 35, loss in basal area due to defoliation can be determined by comparing the actual growth curve with the anticipated growth trend. This loss was read directly from the curve and merchantable loss in cubic feet was determined by Smaalian's formula¹. Bark is not included in any of these computations.

Loss in basal area for the 197 shortleaf and 23 Virginia pines was also computed from basal area graphs. In this case, however, the actual growth for the average tree of each species was compared with the basal area curve of lightly defoliated trees from nearby stands. The volume loss was determined from this difference in basal area by use of the following formula:

$$\text{Volume Loss Per Tree} = \frac{\text{Loss in BA (sq. ft.)}}{2} \times \text{Total Height (Ft.)}$$

The average shortleaf pine was found to be 6.8 inches in diameter (i.b. at 4.5 feet), 35 years of age and 52 feet tall. Virginia pine in the same even-aged stands averaged 54 feet in total height, and 6.7 inches in diameter (i.b. at 4.5 feet).

Normal stand tables (20) predict a total of 490 dominant and codominant shortleaf pines at age 35 on site 60. This same publication indicates that anticipated annual growth would be 1.17 cords per acre per year. These figures were used to estimate volume loss per acre.

A portion of the total loss in basal area (and volume) in shortleaf pine was expressed in the first year of severe defoliation (1957 for Stand 9 and 1958 for Stands 1-8). The loss was compounded by

1/ Volume determination based on total merchantable length was compared with that based on the sum of the individual sections for the four sample trees. Variation was found to be less than 0.1 cubic foot per tree.

a second successive year of defoliation and recovery of the normal rate of basal area increase as measured at breast height was delayed for two growing seasons following cessation of severe defoliation. Return to the normal rate of basal area increase is evident earliest in the upper portion of the bole (Fig. 24). The normal rate of basal area increase at DBH was regained by 1961.

Volume loss sustained by the average shortleaf pine in Stand 9, which suffered three successive years of nearly complete defoliation, amounted to 0.76 cu. ft. per tree over a four year period (Fig. 22). This loss was significantly greater than the 0.28 cu. ft. suffered by the average tree in the other seven stands (Fig. 20). However, youthful vigor and wider spacing in Stand 9 apparently contributed to a more rapid recovery (Fig. 22).

Virginia pine suffering similar defoliation showed a similar pattern of basal area loss. The rate of basal area increase remained below normal for only one growing season following the cessation of severe defoliation (Fig. 21).

No mortality of shortleaf or Virginia pine could be attributed directly to sawfly defoliation. The slowness of recovery in shortleaf pine is indicative of the impact resulting from several successive years of severe defoliation. Normal rainfall characterized the years when defoliation was most severe. Increasing losses from bark beetles following severe defoliation did not occur. Two successive years of severe defoliation of shortleaf pines did result in obvious thinning of the crowns and—on the poorer sites—a yellowing and shortening of the needles. This visible effect was still obvious for one full year following cessation of severe defoliation. Defoliated Virginia pines were not so obviously affected.

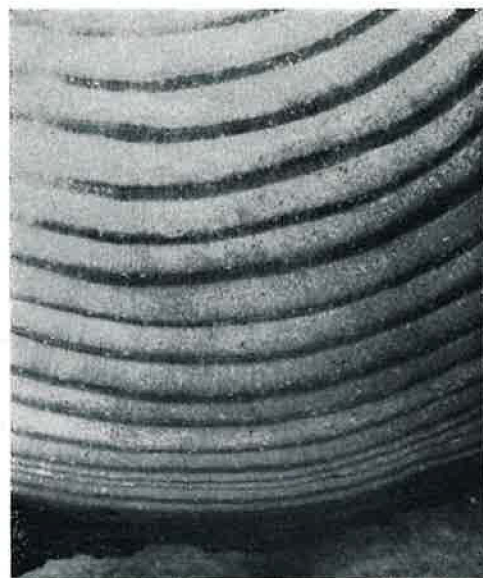


Figure 25. Growth reduction due to sawfly defoliation as seen at the 30 foot sampling point in Tree No. 35 (Fig. 24). The annual rings laid down during periods of severe defoliation and recovery are characterized by reduced summerwood.

SUMMARY

- (1) The "average" shortleaf pine in Piedmont Virginia suffered two successive years of 55% defoliation in 1958 and 1959. Loss in volume per tree was found to be 0.28 cu. feet. Based on available stand tables for dominants and codominants only, this

amounted to 1.5 standard cords per acre over a four year period. This loss constituted 33 percent of the anticipated growth of 4.68 standard cords per acre for that period.

- (2) Virginia pines growing in the same stands lost 0.15 cubic feet of wood volume per tree, about one-half that sustained by the shortleaf pine. Virginia pine also recovered its normal rate of increase in basal area more rapidly than shortleaf.
- (3) Basal area proved to be a simple yet accurate vehicle admirably suited for determination of volume loss in this study.
- (4) The initial year that moderate to severe defoliation occurs can be determined by use of basal area curves. These curves also accurately indicate time of recovery.
- (5) Curves of radial increment show that growth loss in shortleaf pine caused by defoliation by *N. pratti pratti* is expressed the same year in all parts of the stem and is proportional throughout the merchantable length (Fig. 23).
- (6) Defoliation of less than 20% resulted in negligible volume loss. Loss in volume was proportional to degree of defoliation when defoliation exceeded 20% (Fig. 24).

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