Environment Canada
Environnement Canada

Forestry Service
Service des Forêts

BIOLOGICAL CONTROL AGENTS AND THEIR ROLE IN THE POPULATION FLUCTUATION OF THE EASTERN HEMLOCK LOOPER IN NEWFOUNDLAND

by Imre S. Otvos

NEWFOUNDLAND FOREST RESEARCH CENTRE
ST. JOHN'S, NEWFOUNDLAND
INFORMATION REPORT N-X-102

SEPTEMBER, 1973

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

BIOLOGICAL CONTROL AGENTS AND THEIR ROLE IN THE POPULATION FLUCTUATION OF THE EASTERN HEMLOCK LOOPER IN NEWFOUNDLAND

by

Imre S. Otvos

INTRODUCTION

The eastern hemlock looper, Lambdina fiscellaria fiscellaria (Guenée), the western hemlock looper, L.f. lugubrosa Hulst, and the western oak looper, L.f. somniaria Hulst, are closely related species, native to North America. Some species of the biological agents, parasites, predators and diseases, are common to all three of these loopers and are referred to in this report even though the eastern hemlock looper is the only one that occurs in Newfoundland. The eastern hemlock looper has been recorded in Canada from Newfoundland to Saskatchewan, and from the Lake States to the eastern seaboard in the United States (Carroll and Waters, 1967). The western hemlock looper occurs from south-eastern Alaska, through British Columbia and south to Oregon and the western oak looper occurs within the same range (Caroline and Lejenue, 1967).

The eastern hemlock looper is one of the most important pests of balsam fir, Abies balsamea (L.) Mill., in Newfoundland; six outbreaks have been reported on the Island since 1912. The last outbreak that occurred from 1966 to 1972, was the largest recorded and a total of about 2.5 million acres were treated with insecticide in 1968 and 1969 to reduce damage (Otvos et al., 1971).

This report briefly reviews the effect of biotic factors in the collapse of looper outbreaks in North America and discusses the history of the introduction of pathogens and parasites against the eastern hemlock looper in Newfoundland up to 1969. The report also presents the results of studies initiated in that year to examine the potential value of native and introduced biotic agents in controlling looper outbreaks with special reference to birds, parasitic insects, viruses, and fungi.

LITERATURE REVIEW OF BIOTIC FACTORS EFFECTING LOOPER OUTBREAKS IN NORTH AMERICA

The literature indicates that outbreak patterns of the three looper species are similar and that factors influencing the collapse of outbreaks are also similar. As indicated by the eastern hemlock looper in Newfoundland, outbreaks tend to last from 5 to 7 years with 3 to 5 years between cycles; individual infestations last about 2 years. Although the precise cause of the collapse of outbreaks has not been determined, it has been attributed to the effect of climate (Watson, 1934), parasites (Chrystal, 1916), virus disease (Sager, 1957), and a combination of these factors including starvation (Carroll, 1956). Invertebrate predators (de Gryse and Schedl, 1934), birds (Hopping, 1934), and fungi (Fracker and Granovsky, 1927) have been reported as having only a minor influence on the collapse of outbreaks.

Predators

In Ontario, de Gryse and Schedl (1934) observed a few ground beetles and three Hemiptera, Podisus serieventris Uhler., P. maculiventris Say, and Phytocoris angustus Reuter, feeding on larvae of the eastern hemlock looper. Hopping (1934) noted an undetermined hemiterous nymph and large black wood ants (probably Camponotus sp.) feeding on western hemlock looper larvae. He also observed several birds: the yellow warbler, Dendroica aestiva Gmelin, junco, Junco hyemalis oregonus Townsend, white-crowned sparrow Zonotrichia leucophrys Foster, chicadee, Parus (=Penthestes) rufescens Townsend, and an undetermined kinglet feeding on this looper. Carroll (1956) noted the white-throated sparrow, Zonotrichia albicollis (Gmelin), feeding on the eastern hemlock looper.

Parasites

Chrystal (1916) credited an undetermined tachina fly with the control of a western hemlock looper outbreak in British Columbia about 1910. However, Hopping (1934) showed parasites to be of little importance in controlling this insect. Although Hopping (1934) reported three species of Diptera and 11 species of Hymenoptera attacking the looper; the highest parasitism noted was 21.7%. He considered a tachina fly, Winthemia cilitibia Rand., the most effective parasite of the western hemlock looper, even though he found 25% parasitism of the eggs by another species in one area. Campbell (1946) reported 30.6% egg parasitism in a subsequent outbreak from the same Province. In Ontario, de Gryse and Schedl (1934) reared four dipterous and eight hymenopterous parasites from the eastern hemlock looper. The combined parasitism by these 12 species was 20.1%; 8.3% by Diptera and 11.8% by Hymenoptera. Carroll (1956) reported three dipterous and nine hymenopterous parasites reared from the hemlock looper in Newfoundland. His studies showed that Aoplus velox (Cress.) was the most common parasite in 1950 when it parasitized about 32% of looper pupae; however, in 1951 the larval parasite Apanteles sp. nr. flavovariatus (Mues.) was the most numerous, parasitizing 30% of the larvae. Parasitism by Diptera was negligible in both years.

Pathogens

Information on pathogens infecting the looper is incomplete and somewhat contradictory. Nuclear polyhedrosis viruses have been reported in the oak looper (Morris, 1962), and its close relative, the western hemlock looper from British Columbia (Sager, 1957) and from Alaska (Torgersen and Baker, 1967). In 1963 a nuclear polyhedrosis virus was also identified from looper larvae collected in Newfoundland (Cunningham, 1970a). Hopping (1934) reported two fungi, Entomophthora (=Empusa) rhizospora, and another undetermined species attacking the western hemlock looper. Fletcher (1893) reported the fungus Beauveria (=Sporotrichum) globuliferum (Speg.) on the oak looper. The latter fungus was also reported from eastern hemlock looper larvae and pupae in the eastern and central United States (Fracker and Granovsky, 1927; Houser, 1927). In Newfoundland wide spread mortality caused by an undetermined "wilt disease" was noted by Sheppard (1950) but no noticeable recurrence of disease was observed in later years (Carroll, 1956). None of these references provide a basis for assuming that pathogens are consistently responsible for causing the collapse of looper outbreaks in North America. This early information on the incidence of diseases in the looper population was usually based on studies conducted for only 1 or 2 years. None of the biotic factors were examined through the entire course of an outbreak, a basic criterion for evaluating the role of biotic agents in the natural control of an insect species.

BIOTIC AGENTS INTRODUCED INTO NEWFOUNDLAND UP TO 1969

In the late 1940's and early 1950's attempts were initiated to control the hemlock looper on the Island by the introduction of a parasitic fly and a pathogen (Reeks, *et al.*, 1949).

Parasite

Several colonies of *Winthemia occidentis* Reinhard, a tachina parasite of the western hemlock looper and the oak looper, were introduced from British Columbia into Newfoundland between 1949 and 1951 (McGugan and Coppel, 1962, Clark *et al.*, 1973). Release points and the number of parasites liberated are shown in Table 1. Several tachina larvae were collected in the field in 1951 and tentatively identified as *W. occidentis* but they failed to overwinter and could not be positively identified (Carroll, 1956). No positive recoveries were obtained until 1969 (Otvos, 1973).

The liberation of some of these colonies was probably not synchronized with the life cycle of the host. In Newfoundland looper pupation usually begins in late July and continues into August. Only the releases in mid-July could be considered as made during the optimum host-parasite synchronization period. *W. occidentis* generally parasitizes fourth instar larvae and several of the releases were made at a time when the target host (looper) was almost exclusively in the pupal stage. Therefore, of the 10 releases made between 1949 and 1951, only five can be considered as made at a suitable time for the establishment of the parasite. Good synchronization was partly impeded by the difficulty in a prompt delivery of the parasites to the release points because of the isolated nature of the looper infestations where releases were made, and an inadequate road network and poor shipping facilities.

Pathogen

In late July and early August of 1948 a virus extract in liquid suspension was applied to looper infested balsam fir stands near Gander Lake and at Bay d'Espoir. The extract was prepared by pathologists of the Insect Pathology Research Institute from looper cadavers collected near Sault Ste. Marie, Ontario.

In the following year only the release site near Gander Lake was checked for evidence of disease but the stand had been cut. No disease and only one, apparently healthy, larva was found on nearby trees (Reeks *et al.*, 1949). However, diseased larvae were collected on Thwart Island, about 35 miles north from the nearest point where the virus was released. In 1950,

Table 1.- Record of releases of the tachina parasite, <u>Winthemia occidentis</u> against the eastern hemlock looper in Newfoundland.

Location	Lat ° '	Long ° '	Date	Number of adults released Male	Female	Total
Grand Lake Road, Humber Dist.	98.40	58.09	28 August 1949	24	46	70
Harpoon R.R., Grand Falls Dist.	48.35	56.38	28 August 1949	28	47	75
Spruce Brook, Humber Dist.	48.46	58.11	24 July 1950	488	491	979
Little Georges, Humber Dist.	48.49	58.06	24-31 July 1950	1,221	1,230	2,451
Red Indian Lake-Millertown Grand Falls Dist.	48.37	57.09	25 July 1950	1,396	1,398	2,794
Spruce Brook, Humber Dist.	48.46	58.11	23 July 1951	149	149	298
French Brook, Humber Dist.	48.08	58.55	24 July 1951	147	147	294
Red Indian Lake, Grand Falls Dist.	48.37	57.09	28 July 1951	148	149	297
Western Blue Pond, St. Barbe Dist.	50.21	57.13	1 August 1951	323	174	497
TOTAL				3,924	3,831	7,755

larvae affected by a "wilt disease" caused by an undetermined pathogen, were reported in all looper infestations examined in widely scattered locations in western Newfoundland (Sheppard, 1950). Carroll (1956) suggested that the wide spread disease did not result from the introduction but rather from a pathogen native to the Island.

STUDIES ON BIOTIC FACTORS, 1969-1972

The severity of the recent hemlock looper outbreak that began in 1966 prompted the initiation of a series of studies in 1969 to evaluate the role of biotic factors in the control of the looper and to explore the possibility of using disease organisms to control this pest. These investigations were conducted in looper infested stands at several locations across the Island (Fig. 1). The length of study in any one location depended on the presence of a looper infestation, and varied from 1 to 3 years.

Predators

No attempt was made during this study to assess the value of invertebrate predators. However, spiders and syrphids occurred in larval collections, but none were observed feeding on the looper. Among the vertebrate predators only birds were examined. These were collected in several looper infested stands in western Newfoundland between July 30 and September 18, 1969, July 4 and September 12 in 1970 and between July 12 and August 3 in 1971. During these periods late instar larvae, pupae, adults and eggs of the looper were present in the area where the birds were collected. Gizzards of the birds were dissected immediately and stored in 70% ethanol to stop autolysis. The contents were examined under a dissecting microscope and the food material classified according to a method described by Otvos and Taylor (1970). Remnants of looper eggs, larvae, pupae and adults were estimated as a percentage of the entire food content of the gizzard for each species.

A total of 140 birds, representing nine families and 29 species, were examined from 1969 to 1971 (Table 2). Hemlock looper made up 45% of the diet of the birds in 1969, 22% in 1970 and 30% in 1971. Estimates of looper population levels were obtained by beating 10 trees per sample area over a 7 ft x 9 ft sheet with a 10 ft pole, 2 weeks prior to the start of bird collection. Larval numbers averaged 148 per tree in 1969, 100 per tree in 1970 and 91 per tree in 1971. The looper population collapsed in the area where the birds were collected in 1971 and no larvae reached the adult stage. Therefore, to make the results of all 3 years comparable, the data had to be recalculated to include only larval and pupal contents of the gizzards. The recalculated data showed that looper larvae and pupae composed 34.5% of the diet of the birds in 1969, 32.2% in 1970, and 29.3% in 1971. These results indicate a tendency for predation by birds to decrease with a decrease in looper numbers. This trend, in conjunction with the relatively high looper content in individual bird gizzards, indicates that birds respond to changes in looper population levels and may add considerably to the combined effect of the biotic agents in reducing looper numbers. However, it is impossible to provide a meaningful evaluation

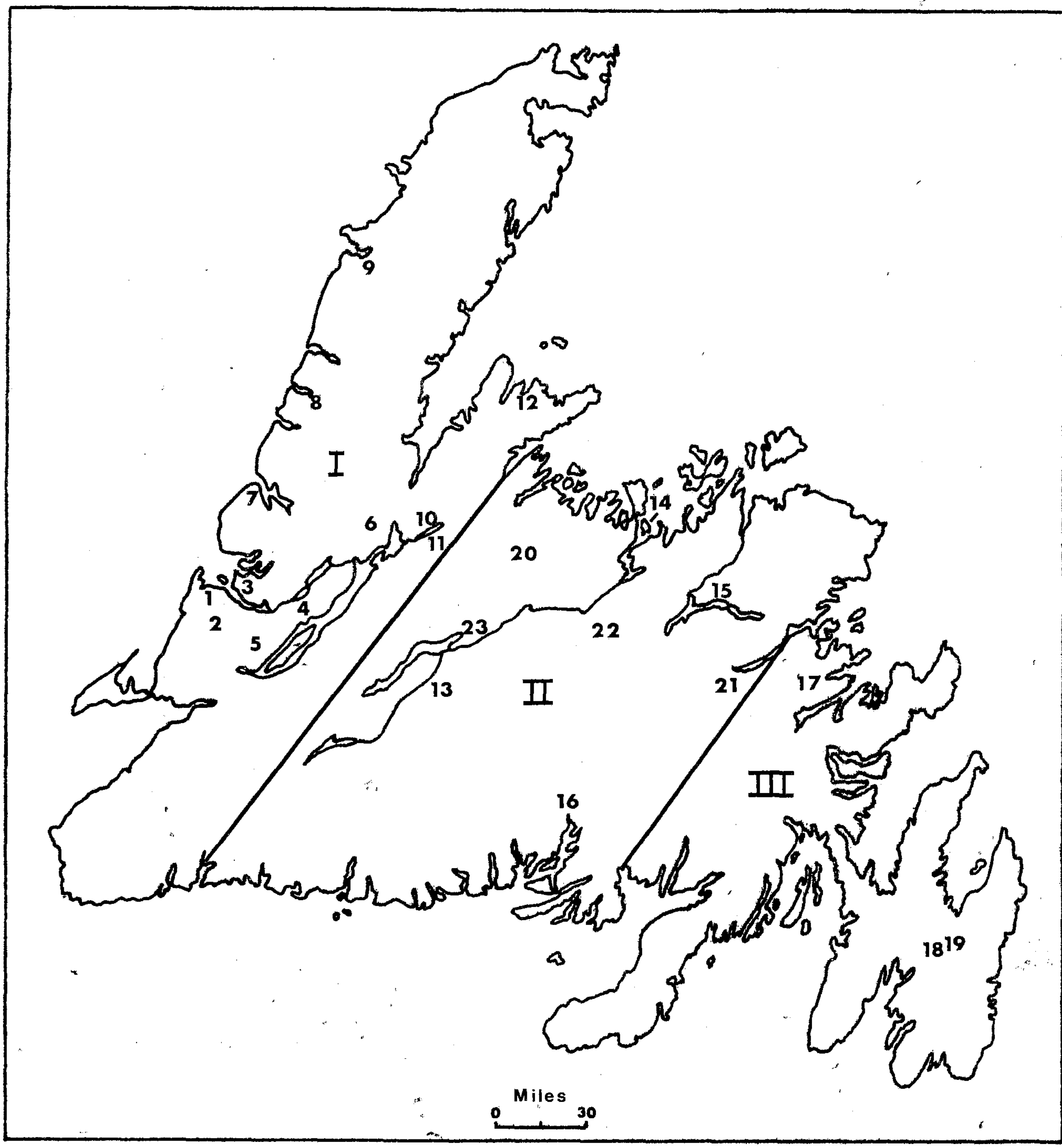

Fig. 1. Major geographic divisions in Newfoundland, study areas and place names referred to in this report.

Legend: I Western, II Central, III Eastern

1 - Frenchman's Cove,
2 - Serpentine Lake,
3 - McIvers,
4 - South Brook Valley,
5 - George's Lake,
6 - Boot Brook,
7 - Bonne Bay,
8 - Parsons Pond,
9 - Hawke's Bay,
10 - Birchy Lake North,
11 - Birchy Lake South,
12 - Ming's Bight,
13 - Lake Ambrose,
14 - Thwart Island,
15 - Gander Lake,
16 - Bay d'Espoir,
17 - Terra Nova Nat'l Park,
18 - Whalen's Lake,
19 - Whisky Pond,
20 - Joe's Lake,
21 - Mint Brook,
22 - Rattling Brook,
23 - Millertown.

Table 2.- Avian predators of the eastern hemlock looper collected in 1969, 1970 and 1971, and the percentage of looper in their diet.

Species	Number of stomachs examined	Looper in diet-% Egg	Larva	Pupa	Adult	Total area occupied by all food particles (mm3)
		1969				
Yellow-bellied flycatcher	3	C(1)[1]	25(3)	0	0	939
Gray jay	4	0	5(1)	0	0	3,136
Black-capped chickadee	8	2(4)	23(5)	44(8)	2(3)	1,903
Boreal chickadee	1	10(1)	0	2(1)	0	102
Hermit thrush	2	16(2)	0	43(2)	0	751
Black-and-white warbler	2	5(1)	30(1)	28(1)	5(1)	609
Tennessee warbler	1	0	7(1)	77(1)	0	375
Myrtle warbler	2	C(1)	0	0	0	900
Black-throated green warbler	3	5(2)	42(3)	40(3)	4(2)	792
Blackpoll warbler	1	4(1)	30(1)	32(1)	14(1)	496
Northern waterthrush	1	0	20(1)	0	0	50
Mourning warbler	1	0	0	30(1)	0	253
Common yellowthroat	1	1(1)	0	7(1)	0	151
Purple finch	2	C(1)	0	46(2)	0	420
Pine grosbeak	11	6(7)	20(7)	39(9)	0	8,541
White-throated sparrow	7	C(1)	12(4)	0	0	3,166
Total	50	(23)	(27)	(30)	(7)	
		1970				
Yellow-bellied flycatcher	2	6(1)	4(1)	7(1)	37(1)	506
Gray jay	3	C(1)	0	0	C(1)	8,972
Black-capped chickadee	5	1(3)	9(1)	0	1(2)	2,009
Boreal chickadee	1	0	0	2(1)	0	291
Swanson's thrush	5	0	22(3)	0	0	3,488
American robin	3	0	1(1)	0	0	1,104
Black-and-white warbler	1	0	0	6(1)	0	335
Black-throated green warbler	4	3(1)	18(2)	15(1)	8(1)	1,051
Blackpoll warbler	2	17(2)	0	1(1)	11(2)	589
Mourning warbler	1	0	15(1)	0	0	289
Yellow warbler	2	0	44(1)	1(1)	0	921
Pine grosbeak	7	0	49(5)	0	0	7,937
White-throated sparrow	4	0	30(2)	0	0	2,469
Total	40	(8)	(18)	(6)	(5)	
		1971				
Yellow-bellied flycatcher	1	0	30(1)	0	0	100
Black-capped chickadee	8	0	28(5)	13(3)	0	720
Boreal chickadee	6	0	19(3)	10(4)	0	1,000
Hermit thrush	1	0	14(1)	0	0	350
Black-and-white warbler	2	0	0	48(2)	0	250
Northern waterthrush	2	0	21(2)	0	0	350
White-throated sparrow	1	0	20(1)	0	0	500
Total	21	(0)	(13)	(9)	(0)	

[1] Figures in parenthesis indicate number of stomachs in which the food was found.
C = trace.

of the importance of birds as predators on the looper without a more detailed study. Such an undertaking was beyond the capacity of the current investigations.

It is interesting to note that brook trout, Salvelinus fontinalis Mitchill, were observed taking hemlock looper larvae floating in creeks running through looper infested stands. When looper larvae were hand picked and thrown into the water, trout would invariably rise to eat them. Although this behaviour was noted on numerous occasions, fish, because of their habitat, can only be considered as incidental predators of the looper.

Parasites

A rearing program was conducted to determine the number and kinds of parasites attacking the looper. Recoveries were made from three stages and are discussed below.

Egg parasites - Looper eggs are minute, usually occur singly and are cemented to a variety of substrates including barks of trees, lichens on the stem of trees and moss on the forest floor. Birch bark and moss samples from the forest floor were collected from various infestations across the Island in the spring of 1969, 1970, 1971 and 1972. The eggs were extracted from the samples by a method described by Otvos and Bryant (1972) and stored at 34°F and 90% R.H. after which they were reared at 70°F and at 70% R.H. until emergence of the host larvae and parasite adults was completed. Egg parasitism was expressed as a percentage of the number of eggs from which parasites emerged.

A total of about 1,900 hemlock looper eggs were reared over the four-year period. Parasitism was low in all years (Table 3), and all parasites were identified as Telenomus sp. Of the 108 parasites reared, only one emerged from eggs collected from moss samples; the balance came from eggs obtained from birch bark samples. This indicates that parasite adults oviposit primarily in exposed looper eggs, such as those on tree trunks, rather than in eggs in the moss on the ground, a factor to be considered in sampling for egg parasites.

Parasitism of eggs collected from birch bark varied with the year and location of sample areas. It averaged 3.9% in 1969, 6.3% in 1970, 22.7% in 1971 and 1.5% in 1972. Over the 4 years parasitism varied from 1.6% to 48.0% between locations. Parasitism increased with the age of the outbreak and reached a high of 22.7% in the fifth year when the outbreak was on the decline. The percent parasitism obtained during the present study was about the same as that reported by Hopping (1934) and Campbell (1946) for the western hemlock looper. In general, percent parasitism of the eggs was low, and these parasites cannot be considered to contribute appreciably to the collapse of looper outbreaks. However, they may be of considerable importance in isolated infestations as shown by the data from Ming's Bight (Table 3) where nearly 50% of the eggs were parasitized in 1971, the year before the infestation collapsed.

Table 3.- Hatching success of hemlock looper larvae and percent parasitism in four generations from 1969 to 1972.

Location	Sample substrate	No. looper eggs reared	Percent hatching	Percent parasitism
		1969		
Mint Brook	Birch bark	411	32.8	2.4
	Moss	68	23.5	0
Millertown	Birch bark	139	62.8	7.9
	Moss	87	49.4	1.1
Rattling Brook	Birch bark	100	54.0	6.0
	Moss	33	33.0	0
Bay d'Espoir	Birch bark	62	50.0	1.6
	Moss	10	33.3	0
Sub-total[1]	Birch bark	712	43.1	3.9
	Moss	198	36.9	0.5
Total[1]		910	41.8	3.2
		1970		
Bay d'Espoir	Birch bark	10	33.3	0
Frenchman's Cove	Birch bark	56	67.9	12.5
McIvers	Birch bark	4	100.0	0
Boot Brook	Birch bark	7	85.7	0
Birchy Lake south	Birch bark	100	60.0	4.0
Total		177	63.0	6.3
		1971		
Frenchman's Cove	Birch bark	38	26.3	15.8
	Moss	3	0	0
Birchy Lake south	Birch bark	183	39.3	16.9
	Moss	115	35.6	0
Ming's Bight	Birch bark	52	19.2	48.0
	Moss	10	10.0	0
Sub-total	Birch bark	273	33.7	22.7
	Moss	128	32.8	0
Total		401	33.4	15.5

Table 3.- Hatching success of hemlock looper larvae and percent parasitism in four generations from 1969 to 1972 - concluded.

Location	Sample substrate	No. looper eggs reared	Percent hatching	Percent parasitism
		1972		
Salmonier Line				
Whalen's Lake	Birch bark	286	62.2	2.1
	Moss	77	70.1	0
Whisky Pond	Birch bark	34	100	0
	Moss	0	0	0
Sub-total	Birch bark	320	66.3	1.9
	Moss	77	70.1	0
Total		397	67.0	1.5

[1] Percentage data are averages for each year computed from the raw data.

Larval and pupal parasites - Percent parasitism was estimated from both larvae and pupae collected throughout the season and reared in an insectary.

In 1969, 1970 and 1972, larvae and pupae were reared from collections made at irregular intervals from the locations shown in Table 4. In addition, in 1970 and 1971, larvae were collected at the south side of Birchy Lake at 3 to 4 day intervals from June 25 to August 14. In all areas larvae were sorted and reared by instar to determine what instars were attacked. All larvae were collected by beating the foliage of sample trees over a 7 ft x 9 ft beating sheet. In 1970 and 1971, 10 trees were sampled for each sample period. In 1969 and 1972 no consistent number of trees were sampled for any period. In all years pupae were collected by beating trees and in traps (Otvos submitted for publication[1]).

The insects were reared in a field insectary where temperatures ranged from 50°F to 88°F and relative humidity ranged from 32% to 94%.

Percent parasitism by the hymenopterous group was estimated from the total number of Hymenoptera larvae and adults that emerged from the host. Larvae of the parasites all emerged from host larvae and adults from host pupae. A high proportion of the parasite larvae spun cocoons and completed development to the adult stage. All adults were forwarded to the Entomological Research Institute (E.R.I.) Ottawa for identification.

[1] Otvos, I.S. A method for collecting pupae of the eastern hemlock looper (submitted to the Canadian Entomologist).

Table 4.- Larval and pupal parasitism of the eastern hemlock looper in Newfoundland by location, 1969-1972.[1]

Location	No. host collected	No. collections	Percent parasitism by Diptera	Percent parasitism by Hymenoptera
		1969		
Terra Nova Nat'l. Park	469	2	1.5	1.7
McIvers	233	1	3.0	0.1
Serpentine Lake	141	1	34.0	0.7
Frenchman's Cove Plot A	3,967	4	14.8	0.9
Total[2]	4,810		13.5	1.0
		1970		
Frenchman's Cove Plot A	1,333	11	42.9	0.1
Plot B	6,793	17	18.1	0.8
Plot C	571	5	27.1	0.2
Birchy Lake north	599	5	10.7	0.2
Birchy Lake south	3,551	8	3.7	0.7
Total	12,847		16.8	0.6
		1971		
Birchy Lake south	3,307	12	18.7	0.1
Ming's Bight	8,843	8	47.3	1.3
Lake Ambrose	186	2	23.1	0
Total	12,336		39.3	1.0
		1972		
Ming's Bight	477	5	65.8	0.4

[1]Based on laboratory rearings of field collected 3rd and 4th instar looper larvae and pupae.

[2]Percent parasitism was calculated as an average for each year.

Percent parasitism by Diptera was estimated both from larval and pupal collections as follows: (a) host collected as larvae - all larvae carrying dipterous eggs were considered parasitized; (b) host collected as pupae - parasitism was based on the number of mature dipterous larvae reared from the total number of pupae. As with Hymenoptera, adult Diptera were also sent to Ottawa for positive identification. In 1969 and 1970 few Diptera larvae completed development to the adult stage. However, a new rearing technique was developed in 1971 (Otvos, 1973) and from this year on most dipterous larvae were reared successfully to the adult stage.

A total of 30,470 loopers (14,963 3rd and 4th instar larvae and 15,507 pupae) were collected and reared for parasite emergence from 1969 to 1972. Table 4 summarizes the percent parasitism by both Diptera and Hymenoptera by sample area for each year.

Twelve species of primary parasites were reared from the eastern hemlock looper during the study (Table 5). These include the following four tachina flies: Blondelia eufitchiae (Tns.), Madremyia saundersii (Will.), Phryxe pecosensis (Tns.), Winthemia occidentis Rnd., and eight hymenopterous species: Aoplus velox (Cress.), Apechthis ontario (Cress.), Itoplectis conquisitor (Say), Apanteles sp., Phobocampe sp., Zele sp., and one undetermined species from the sub-family Porizontinae and an undetermined species of the subtribe Acrolytina. In addition two hyperparasites, Mesochorus discitergus (Say) and Dibrachys cavus (Wlk.) were also reared during the study. Hyperparasites or secondary parasites attack primary parasites and thus reduce the effectiveness of the latter. However, the occurrence of these two hyperparasites in Newfoundland is relatively rare, only a total of six specimens were reared during the study. Therefore, their effect on the primary parasites is considered negligible. This list includes six primary and two secondary parasites that had not been recorded previously in Newfoundland (Table 5 and 6). Table 6 also shows that three, possibly four, species reared in earlier studies (Carroll, 1956), did not occur in the rearings conducted between 1969 and 1972 and that 19 species of parasites that attack the eastern and western hemlock looper elsewhere in Canada and in Alaska apparently do not occur in Newfoundland. Two of the primary parasites, Winthemia occidentis and Itoplectis conquisitor, reared during the current study, are of special interest. The former was introduced against the eastern hemlock looper during the years 1949 and 1951 (McGugan and Coppel, 1962), however it was not recovered until 1969. The latter was introduced against the blackheaded budworm, Acleris variana Fern., in 1950 and has since transferred to the looper.

Parasitism by Diptera, generally increased as the outbreak progressed (Table 4). In areas where defoliation was noticeable for the first year (Terra Nova Nat'l Park, McIvers, Frenchman's Cove - Plot A in 1969, south side of Birchy Lake in 1970), parasitism by Diptera was low (1.5%, 3.0%, 14.8% and 3.7% respectively). However, where defoliation had occurred for at least 2 consecutive years, such as Serpentine Lake in 1969 and Frenchman's Cove - Plot A in 1970, parasitism was much higher (34.0% and 42.9% respectively). During the period 1969-72 parasitism by Hymenoptera species was only about 1%, whereas the average parasitism by Diptera species ranged from 14% in 1969 to 69% in 1972 (Table 4); parasitism by the latter group varied from a low of 1.2% to a high of 86.9% among the locations sampled. Conversely, results of rearings conducted in 1951 and 1952 showed that parasitism by Hymenoptera was 32% and 30% respectively, whereas parasitism by Diptera was negligible (Carroll, 1956).

Table 5.- Parasites reared from the eastern hemlock looper in Newfoundland, 1969-1972.[1]

Species	1969	1970	1971	1972
DIPTERA				
Tachinidae				
Blondelia eufitchiae	X	X	X	
Madremyia saundersii	X	X		
Phryxe pecosensis	X	X		
Winthemia occidentis[2]	X	X	X	X
HYMENOPTERA				
Ichneumonidae				
Aoplus velox	X			
Apechthis ontario		X	X	X
Itoplectis conquisitor[2]		X	X	
Mesochorus discitergus[2,3]		X		
Porizontinae[2] (subfamily)	X			
Acrolytina[2] (subtribe)		X		
Phobocampe sp.[2]		X		
Braconidae				
Apanteles sp.	X	X		
Zele sp.[2]	X	X		
Pteromalidae				
Dibrachys cavus[2,3]		X		

[1]Determinations were made by specialists of the Entomology Research Institute, Agriculture Canada, Ottawa; Drs. W.R. Mason (Braconidae), J.R. Barron (Ichneumonidae), C.M. Yoshimoto (Pteromalidae), D.M. Wood (Tachinidae).

[2]New records.

[3]Hyperparasites.

Table 6.- Larval and pupal parasites reported from the eastern hemlock looper in Newfoundland and Ontario, and from the western hemlock looper in British Columbia and Alaska.

Parasite	Nfld.	Ont.	B.C.	Alsk.
DIPTERA				
Sarcophagidae				
Pseudosarcophaga (=Agria) affinis (Fall.)			X[1]	
Tachinidae				
Blondelia (=Anetia = Lydella) eufitchiae (Tns.)	X[2,3]	X		
Erycia rutila Meig.		X		
Eusisyropa (=Zenillia) blanda (O.S.)			X	
Madremyia saundersii (Will.)	X[2,3]	X		
Phryxe pecosensis (Tns.)	X[2,3]			
Winthemia sp.		X		
Winthemia cilitibia Rand. (=W. occidentis Rand.?)			X	
Winthemia occidentis Rnd.	X[3]			
HYMENOPTERA				
Ichneumonidae				
Aoplus (=Amblyteles) cestus (Cress.)			X	
Aoplus (=Amblyteles) velox (Cress.)	X[2,3]	X		
Aoplus (=Amblyteles) sp. nr. velox Cress.			X	
Aoplus velox occidentalis (Harr.)				X
Aoplus velox (=Ichenumon puerilis)(Cress.)			X	
Apechthis (=Ephialtes) sp.				X
Apechthis ontario (Cress.)	X[2,3]		X	X
Cratichneumon ashmeadi (Schulz)				X
Dusona (=Campoplegidea) ellopiae (Walley)		X		
Gelis ferruginosus Cush.[4]			X	
Hemiteles sp.[4]		X	X	
Itoplectis (=Ephialtes) sp.			X	
Itoplectis conquisitor (Say)	X[3]	X		
Itoplectis obesus Cush.			X	
Itoplectis quadricingulatus (Prov.)				X

Table 6.- Larval and pupal parasites reported from the eastern hemlock looper in Newfoundland and Ontario, and from the western hemlock looper in British Columbia and Alaska. - concluded.

Parasite	Nfld.	Ont.	B.C.	Alsk.
Mastrus aciculatus (Prov.)	X[2]			
Mastrus laplantei Mason				X
Mastrus neodiprioni Vier.[4]			X	
Mesochorus discitergus (Say)	X[3]			
Phaeogenes gaspesianus Prov.	X			
Phobocampe sp.	X[3]			
Phobocampe (=*Hyposoter*) sp. nr. *geometrae* Ashm.			X	
Pimpla aquilonia Cress.	X[2]			
Pimpla hesperus (Tow.)				X
Pimpla (=*Ephialtes*) *pedalis* Cress.	X	X		X
Porizontinae (subfamily)	X[3]			
Acrolytina (subtribe)	X[3]			
Braconidae				
Apanteles sp.	X[3]			
Apanteles sp. nr. *flavovariatus* Mues.	X[2]			
Rogas sp.	X[2]			
Zele sp.	X[3]	X		
Pteromalidae				
Dibrachys sp.[4]		X		
Dibrachys cavus[4] (Wlk.)	X[3]			
Pteromalus puparum (L.)		X		

[1]Records for Alaska are from Torgersen (1971), B.C. from Hopping (1934), Ontario from de Gryse and Schedl (1934) and for Newfoundland from[2] Carroll (1956) and[3] those obtained during 1969 and 1972 studies.

[4]Hyperparasite.

The reversal in parasitism by the two groups during the two outbreak periods appears to be related to the emergence of W. occidentis as the dominant parasite. This parasite has just been released prior to the investigation in 1950 and 1951; consequently its effect was negligible (in fact undetected) compared to the mortality caused by the native parasites. However, during the next 20 years W. occidentis has become the most prevalent parasite of the hemlock looper on the Island.

The most common hymenopterous parasites were the two introduced species, I. conquisitor and A. ontario. They were introduced against the blackheaded budworm in 1950 and against the spruce budworm in 1947 and 1951 respectively.

The seasonal progression of parasitism by tachina flies is illustrated in Fig. 2. The data from 1969-72 studies showed that activity of these parasites began about the first week in July, and percent parasitism increased slowly as the season progressed reaching a peak about the time pupation of the host started. Most of the parasitization occurred on warm, sunny days. All four species laid their eggs on the surface of the dorsal or lateral part of the body near the head of the 4th and occasionally late 3rd instar larvae (Fig.3).

It is interesting to note that dipterous parasites locate their host by hovering over looper infested trees. Looper larvae were frequently observed evading the parasites by dropping off the branch on a silken thread. If oviposition was successful, looper larvae frequently tried to remove the parasite egg by rubbing their bodies against twigs or branches. However, on no occasion was the host observed to be successful in removing a parasite egg. No observation was made on the oviposition behavior of hymenopterous parasites.

Multiple parasitism and superparasitism by Diptera - The female of some parasites have the ability to distinguish between healthy hosts and those already parasitized, and to avoid ovipositing on the latter (Salt, 1934). Others, however, do not have this characteristic or it is not well developed. In the latter case, either multiple parasitism or superparasitism of the host may occur. Multiple parasitism occurs when an individual host insect is infested simultaneously with the young of two or more different species of primary parasites. Superparasitism occurs when more than one parasite of a single species attacks an individual host insect or when one parasite will lay more than one egg on a single host (Smith, 1916).

In the present study it is possible that both types of parasitism occurred on the looper by tachina flies. One W. occidentis female, captured in the field, was caged with 12 4th instar looper larvae. The fly parasitized seven larvae in 2 days with the following result: two larvae had one egg attached, two had two eggs each and the remaining three had three eggs each. Results of this experiment show that W. occidentis may be classed as a superparasite. In the field up to seven parasite eggs have been commonly observed on one host larva (Table 7). The highest number of tachina eggs per host observed in the field was 12 on any one looper larva. Of about 1200 parasitized larvae collected over 3 years, approximately 73% had one egg per host, 19% had two, 5% had three, 2% had four and about 1% of the

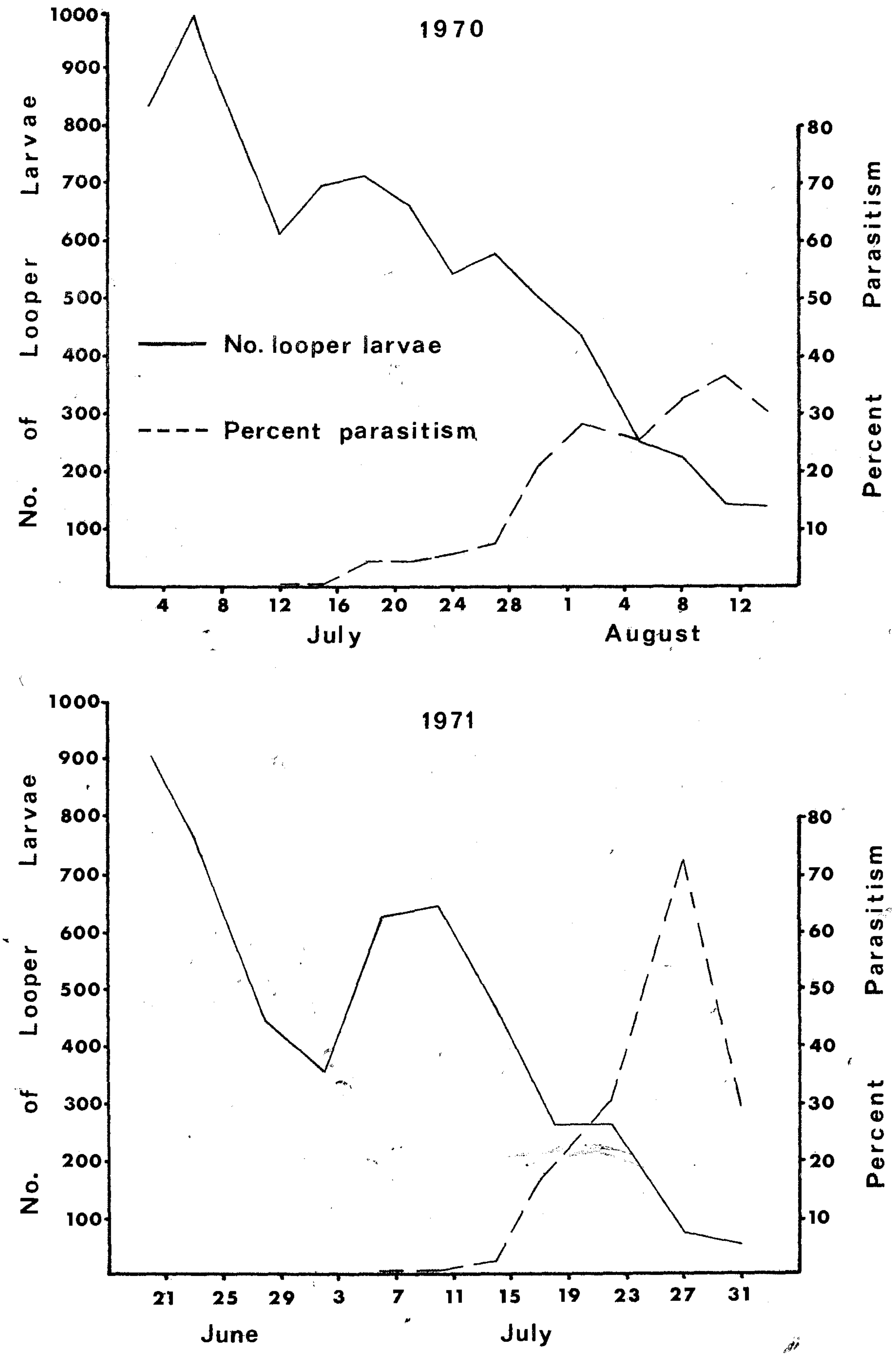

Fig. 2. The increase of percent parasitism by Diptera over the season in 1970 and 1971.

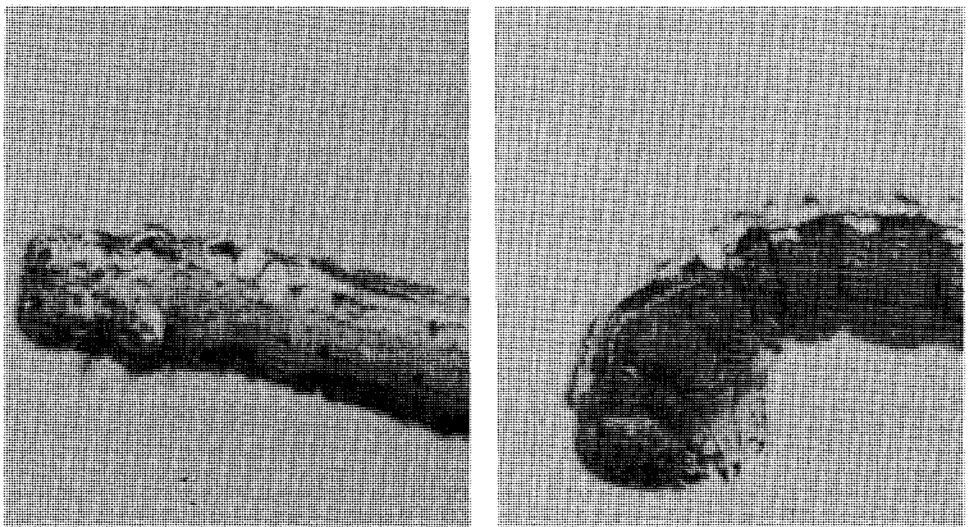

Figure 3. Tachina fly eggs on eastern hemlock looper larvae.

Table 7.- Percentage of hemlock looper larvae having different numbers of tachina fly eggs, 1969-1971.

Collect. date	Number of looper larvae collected	Number of looper larvae parasitized	Proportion of larvae with different numbers of tachina fly eggs per host: 1	2	3	4	5	6	7	8	9	10
			1969 - Frenchman's Cove									
30-7	1,803	221	80.1	16.3	2.7	0.4	0.4					
8-8	910	186	79.5	17.2	2.1	0.5	0.5					
18-8	28	28	71.4	17.9	7.1	3.6						
Total	2,741	435	79.3	16.8	2.8	0.7	0.4					
			1970 - Frenchman's Cove									
18-7	716	32	90.6	9.4								
30-7	508	114	65.8	18.4	8.0	4.4	0.9	1.8				0.9
2-8	443	128	69.5	24.2	6.3							
Total	1,667	274	70.4	20.1	6.2	1.8	0.4	0.7				0.4
			1971 - Birchy Lake									
7-7	622	1	100.0									
11-7	644	6	100.0									
15-7	465	12		16.6	41.6	41.6	41.6					
19-7	263	43	86.0	9.3	4.6							
23-7	262	79	73.4	15.2	6.3	3.8	1.3					
25-7	774	262	71.4	24.0	3.4	0.4	0.8					
28-7	76	55	52.7	14.5	11.0	9.1	5.5	5.5	1.8			
1-8	58	17	41.2	11.8	41.2	5.8						
Total	3,164	475	68.4	19.1	7.2	3.1	1.3	0.6	0.2			
Grand Total	7,572	1,184	72.8	18.5	5.3	1.9	0.8	0.3	0.4			0.1

parasitized larvae had five or more eggs per host. It was not possible to determine if these tachina eggs belonged to one or more dipterous species or if other parasite species had also attacked these hosts, therefore, evidence of multiple parasitism was not shown.

A test was also conducted to determine what proportion of the deposited tachina eggs hatched and eventually emerged from the host as mature larvae. A total of 963 parasitized looper larvae, having from one to 10 tachina eggs attached, were collected in the field and reared individually in the laboratory. The results of this experiment are as follows:

		Number of tachnia eggs per host							
		1	2	3	4	5	6	10	Total
No. of looper reared		727	163	42	20	8	2	1	963
No. of tachina eggs used		727	326	126	80	40	12	10	1,321
No. and sex of emerged looper adults	M	16	3	2	0	0	0	0	21
	F	40	9	2	1	0	0	0	52

The data show that a total of 1,321 tachina eggs were deposited on 963 looper larvae and 92% of these or 890 larvae were killed; the remaining 73 survived to produce 21 male and 52 female moths. These results indicate that 431 tachina eggs or about 33% was "wasted". However, the tabularized data above also show that the eggs were not entirely wasted as mortality of the host increased proportionally with the number of parasite eggs deposited on an individual host. The highest proportion of the parasitized larvae survived when only one tachina egg was deposited on a host, however, all looper larvae died when five or more eggs were deposited on them.

Regardless of the number of tachina eggs deposited on individual looper larvae only one parasite larva emerged from a host in 95% of the rearings. A few hosts produced two parasite larvae and rarely three; when two or more emerged they were usually smaller than those produced singly. Tachina larvae emerged on the average 6.4 days (range 2-9 days, N = 50) after the host pupated.

Results of the experiments also show that parasitism was influenced by the sex of the host. A total of 4,683 looper pupae were collected in the field, sorted by sex and reared separately for parasite emergence. The results are summarized as follows:

Sex	Number of looper		Percent parasitism by	
	Pupa reared	Adult emerged	Diptera	Hymenoptera
Male	2,343	334	35.9	1.1
Female	2,340	1,188	4.8	2.7

The data show that more Diptera larvae emerged from male looper pupae (35.9%, N = 2,343) than from female pupae (4.8%, N = 2,340). The difference was highly significant (X^2 = 699.0, d.f. = 1, P > 0.01). On the other hand more Hymenoptera emerged from female looper pupae (2.7%, N = 2,340) than from male pupae (1.1%, N = 2,343). The difference was again highly significant (X^2 = 15.7, d.f. = 1, P > 0.01). It is not known whether this indicates a preferential oviposition by sex or an encapsulation process such as described by Muldrew (1953) for Mesoleius tenthredinis Morl., a parasite of the larch sawfly, Pristiphora erichsonii (Htg.).

It is impossible to estimate the effectiveness of parasites in controlling looper outbreaks from the results of the studies and surveys conducted to date. Precise estimates can only be provided by studies conducted throughout the duration of an outbreak and in several infestations having a wide range of looper population levels.

Pathogens

Pathogens are disease causing microorganisms. The only ones known to attack the eastern hemlock looper in Newfoundland are viruses and fungi.

Viruses - A "wilt disease", assumed to be a virus, was reported attacking the looper during the 1947-54 outbreak and all the infestations affected collapsed (Carroll, 1956). Therefore, Dr. J.C. Cunningham from the Insect Pathology Research Institute, Sault Ste. Marie, Ontario, conducted several studies in Newfoundland in 1969 and 1970 to determine the feasibility of applying nuclear polyhedrosis viruses as control agents against the eastern hemlock looper.

He found (1970b) that the nuclear polyhedrosis viruses isolated from eastern and western hemlock looper and the oak looper were all equally pathogenic to the eastern hemlock looper in Newfoundland. The virus was applied in suspension (equivalent to about 60 virus killed larvae per gallon) using a mist blower at rates ranging from an equivalent of 150 to 650 Imperial gallons per acre. All three viruses had a long incubation period; death was not observed until 20 days after the application of the virus sprays. Larval mortality was estimated at about 22%, and mortality in the pupal stage as 66% in the sprayed area. The results of these tests showed that the rate and dose of the virus suspension spray were excessive making the method economically prohibitive (Cunningham, 1970a). The year following spraying, treated areas were checked to determine if transovum transmission of the virus had occurred. No virus infected larvae were found suggesting that the nuclear polyhedrosis virus infecting the hemlock looper is not transmitted from one generation to the next even though nuclear polyhedrosis viruses is known to be transmitted in other insects including the gypsy moth, Porthetria dispar (L.) (Doan, 1969).

Fungi - Larval collections in 1969 revealed the presence of a disease previously unreported from the Island. The organisms causing the disease were identified by Dr. D.M. MacLeod of the Insect Pathology Research Institute, as two fungi, Entomophthora sphaerosperma, and a new species. These fungi were recorded from several other locations in the next 3 years (Fig. 4). The epidemiology of these fungi is poorly understood and, therefore, it is impossible to determine with certainty whether the more prevalent status of the fungal disease in the successive years of the outbreak was the result of the natural spread of the disease, or whether it was the result of the more intensive sampling, or both. The effects of these fungi and their apparent value in controlling the latest outbreak are discussed below.

It should be noted that percent infection was estimated at each location at different times (sometimes weeks apart) and at different stages in the development of the looper, therefore, the estimates are not statistically comparable. The information, however, indicates variation in the stage of the host attacked and gives some indication of the effectiveness of the disease as a control agent.

Distribution and natural spread of the disease - In 1969 fungal infection was noted at McIvers, Serpentine Lake, and South Brook Valley. At Serpentine Lake about 20% of the larvae were infected and at McIvers up to 90%. Estimates of the proportion of infected larvae at South Brook Valley could not be made because the area had been treated three times with fenithrothion during a chemical control operation and it was assumed that any larvae that appeared unhealthy were affected by the insecticide. However, subsequent examination of dead larvae from this area showed that nearly 50% contained Entomophthora spp. resting spores. Larval population levels averaged about 35 larvae per tree at all three locations. On rechecking these areas in 1970 only diseased larvae were found at McIvers; no diseased larvae and only one, apparently healthy, larva at South Brook Valley, and no looper larvae were found at Serpentine Lake.

Fungal infection was found at five other locations in 1970: at Frenchman's Cove about 5% of the late instar larvae were infected; at Boot Brook about 80% of late instar larvae were infected; at the north and south side of Birchy Lake about 15% of the late fourth instar larvae and 20% of the pupae were infected. At Joe's Lake in central Newfoundland fungal infection was observed among dead and dying larvae, but percent infection and larval population levels were not estimated at this location. Larval samples averaged 15 per tree at Boot Brook, 90 at Frenchman's Cove, and 80 per tree at the north and south side of Birchy Lake.

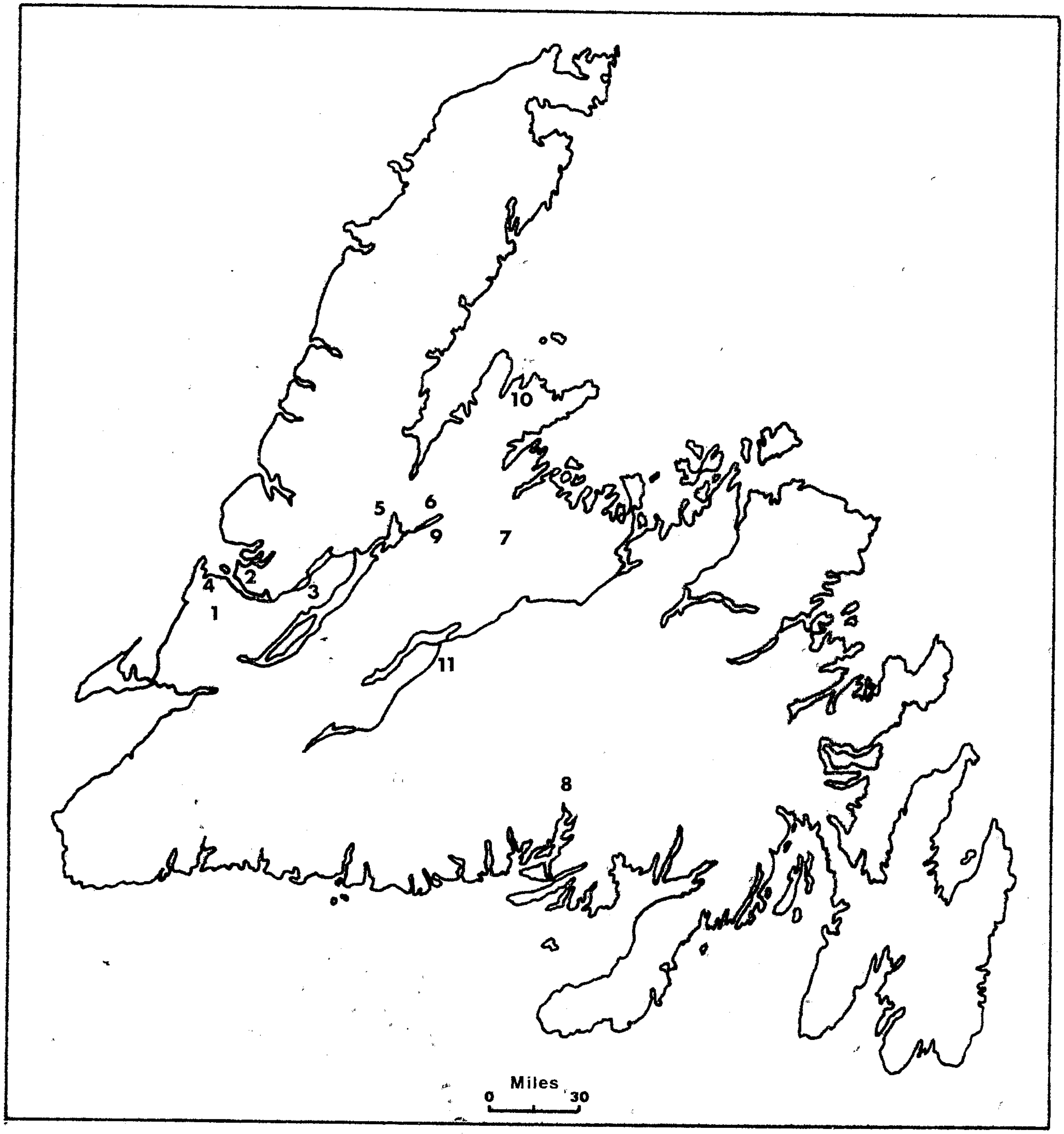

Fig. 4. Collection records of two fungal diseases of the eastern hemlock looper in Newfoundland.

Legend

1969	1 - Serpentine Lake,	2 - McIvers,	3 - South Brook Valley;
1970	4 - Frenchman's Cove,	5 - Boot Brook,	6 - Birchy Lake north
	7 - Joe's (Badger) Lake,	8 - Bay d'Espoir;	9 - Birchy Lake south
1971	9 - Birchy Lake south,	10 - Ming's Bight,	11 - Lake Ambrose
1972		10 - Ming's Bight	

In 1971 infected larvae were collected at Lake Ambrose, Birchy Lake south and Ming's Bight. Infection was first noted at Lake Ambrose, on July 9. Most of the larvae were in the 2nd instar and about 15% were diseased. Larval numbers averaged 400 per tree, however, numbers dropped to 25 per tree by mid-July when infection was about 90%, and no larvae or pupae were found at the end of the month. The looper infestation at the south side of Birchy Lake averaged 91 larvae per tree in late June, however, by the end of July looper numbers decreased to six per tree and even these were either diseased or parasitized by tachina flies or both. Fungal infection was observed on July 25 at Ming's Bight; larval numbers averaged 250 per tree and about 7% were infected. A few 1st instar larvae were collected in this area in June of 1972, but no looper larvae or pupae were found during subsequent sampling in July and August.

The progress of the fungal disease in an infestation was followed more closely by continuous sampling of a looper infestation at the south side of Birchy Lake. The results showed that percent infection increased as the season progressed (Table 8). Although the incubation period of the fungus under natural conditions is not known, the data show that the disease requires several weeks to spread to most of the larvae in a population. Weather conditions, as recorded in the area, appeared to influence the rate of infection. Percent infection increased to about 13% in the week of July the 11th, during a period of almost continuous rainfall. Mean temperature during this period was about 60°F. During the next few days the temperature averaged only about 55°F and the relative humidity fell to less than 70%; fungal infection during this period declined to about 8%. Following a heavy rainfall on July 20, the temperature rose to a mean of 60°F until the end of the sample period and the mean relative humidity exceeded 70%. Percent infection increased rapidly during this time until it reached a high of 74% on the day of the last sampling date August 1. These observations indicate that fungal epizootics may develop best at a mean daily temperature of above 60°F and at a high relative humidity or when rainfall occurs frequently. In Newfoundland, during the summer months, relative humidity in the crown usually reaches the dew-point at night, providing suitable conditions for fungus development and sporulation even though rainfall may be minimal.

Results of sampling in 1969, 1970 and 1971 indicate that fungal disease was responsible for terminating the outbreak at Serpentine Lake and McIvers in 1969, at Boot Brook and possibly in the Bay d'Espoir area in 1970, and at Lake Ambrose and Birchy Lake in 1971. These results also indicate that the fungi can kill both early as well as later stages of the eastern hemlock looper and may therefore terminate an infestation before defoliation becomes important.

Observations made during the recent study have shown that Entomophthora fungi attacking the eastern hemlock looper larvae in Newfoundland can only be separated from the virus disease, on the basis of external symptoms during the later stages of infection. The symptoms of the fungal disease are as follows.

Table 8.- Progress of infection by Entomophthora spp. in a field population of the eastern hemlock looper in 1971.[1]

Collection date	Number of looper larvae collected	Percent infection
July 3	359	0.6
7	622	0.1
11	644	12.8
15	465	10.8
19	263	7.6
23	262	10.6
25	774	16.1
28	76	60.5
Aug. 1	58	74.1

[1] Ten trees were sampled at each collecting date, using the regular F.I.D.S. tree beating method, except July 25 when 30 trees were sampled.

Just prior to death infected larvae either crawl to a straight surface, such as branches or the underside of needles, where they extend themselves ("stretch out") or hang from the branches usually by their prolegs in a "S" or "J" shape (Fig. 5). Shortly after death and depending on weather conditions, the larvae are first turgid or bloated (Fig. 5a) and burst upon any attempt to pick them off the tree. Later under unfavorable weather conditions the body contents dry out and the body shrivels up, becomes brittle (Fig. 5b, c) and disintegrates easily when lifted. Under warm and humid conditions the fungus readily sporulates on the dead insect (Fig. 5d). Infected larvae that die on the underside of needles or branches in an extended position can dry out to such a degree that they appear as faint, brownish-gray lines. When the disease is caused by the nuclear polyhedrosis virus in the later stage of infection the affected larvae tend to aggregate usually on the leader of the tree. Carroll (1956) described diseased larvae he encountered during an outbreak in 1950 as soft and generally suspended from the needles by their prolegs; occasionally some were stretched full length on a twig or needle, and "... some specimens became covered with white mould shortly after death." Therefore, on the basis of the description of symptoms provided by Carroll (1956) the disease reported in 1950 looper infestation in Newfoundland was probably caused by fungi.

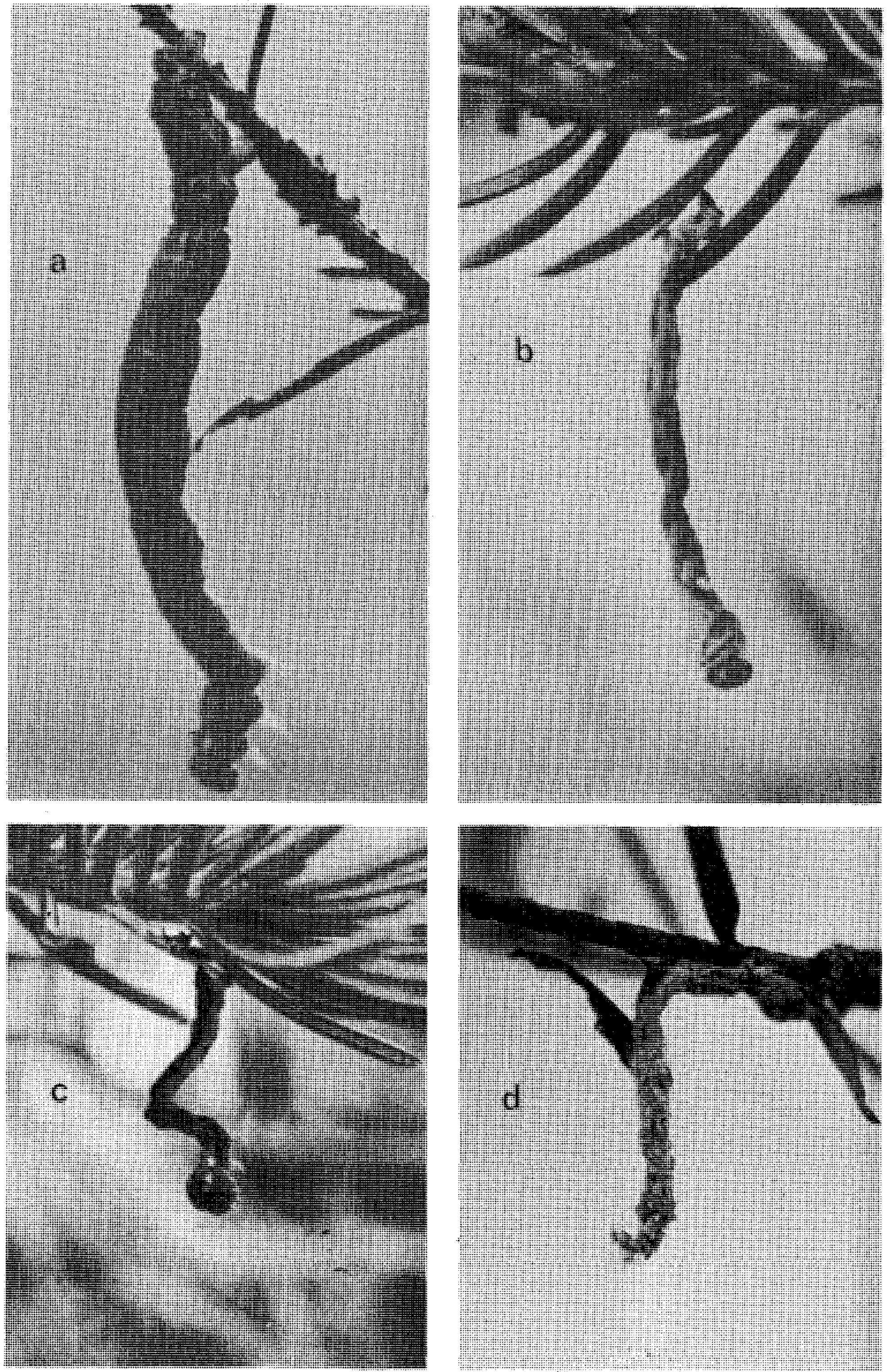

Figure 5. *Entomophthora* spp. infected eastern hemlock looper larvae: a - turgid larva; b and c - desiccated larvae; d - larva engulfed by fungal mat.

Field experiments on artificial spread of fungus - In cooperation with the Insect Pathology Research Institute an experiment was conducted in Newfoundland to investigate the possibility of inducing a fungal epizootic artificially. A manuscript pertaining to this experiment has recently been submitted for publication;[1] the highlights of the results are summarized below.

The results of this field trial show that larvae infected in the laboratory with the protoplast stage of Entomophthora nov. sp. were killed by the fungus, that the fungus sporulated well on the dead insects (Fig. 5d), and that the disease was transmitted from the inoculated larvae to field populations.

The success of the experiment also suggests that hemlock looper infestations may be controlled before significant tree mortality occurs by the early application of this fungus provided that an economic method of mass producing spores can be developed.

Combined Effect of the Different Biological Control Factors - Studies conducted on the eastern hemlock looper showed that under Newfoundland's climatic conditions, two fungal diseases are the most important biotic factors responsible for the collapse of looper outbreaks, although under certain conditions mortality caused by parasitism may also be important.

The two fungal diseases alone are capable of causing the collapse of individual infestations as was illustrated by the infestation at Lake Ambrose where infection occurred in 2nd instar larvae and the infestation collapsed. In another infestation on the south side of Birchy Lake the fungal disease was attributed with killing about 75% of the looper population and tachina flies destroyed the remainder of the looper larvae and pupae; about 20% of the larvae infected with the disease were also parasitized. At the end of the larval period all of the looper larvae in the samples were either diseased, parasitized by tachina flies or both. Even egg parasitism under certain conditions may contribute appreciably to the decline of looper populations. In one locality egg parasitism in combination with low hatching success of looper eggs and the fungal disease, that become evident in the late instars, caused the collapse of the infestation.

SUMMARY AND CONCLUSIONS

Literature on the causes of the collapse of outbreaks of the three closely related loopers is briefly reviewed. Records show that outbreaks of the eastern hemlock looper are cyclic and that biotic factors (predators parasites and diseases) are at least partly responsible for the collapse of outbreaks in Newfoundland.

---

[1] Otvos, I.S., D.M. MacLeod, and D. Tyrrell. Two species of Entomophthora pathogenic to the eastern hemlock looper in Newfoundland (submitted to The Canadian Entomologist).

Studies conducted during the recent looper outbreak have provided more detailed information on the influence of avian predators, and both the native and introduced parasites, and their effect on the course of looper outbreaks in Newfoundland.

Stomach analysis of birds show that at least 19 species of birds prey on the looper. Although all stages of the looper reached a high of 46% of the diet in the birds examined in 1 year it is considered that birds are not a major factor influencing the collapse of outbreaks. Although no precise estimates of bird populations were obtained in the plots, casual observations indicated bird numbers were not high. Furthermore, it is generally recognized that there is a paucity of the bird fauna on the Island compared to that in mainland Canada.

Parasites appear to be more important than avian predators in controlling looper outbreaks. One egg parasite and 12 primary larval and pupal parasites were reared from the looper during this study. The egg parasite, Telenomus sp., caused up to 23% parasitism while the larval and pupal parasites caused up to 79% mortality of looper larvae and pupae. The latter were composed of four dipterous and eight hymenopterous species; of these, dipterous parasites accounted for all but about 1% of the parasitism. Of the Diptera group, Winthemia occidentis, an introduced species, was the most common. Itoplectis conquisitor, another introduced species, was the most common of the Hymenoptera. The level of parasitism by both of these orders appeared to be related to the sex of the host; more dipterous larvae emerged from male than from female pupae, and conversely more hymenopterous parasites emerged from female than from male pupae. Parasitism of all stages of the looper increased as the outbreak developed.

Two native fungi, Entomophthora sphaerosperma and Entomophthora nov. sp. appear to be the primary agents causing the collapse of looper outbreaks in Newfoundland. Data collected during the study suggest that fungal infection builds up in many stands in about 2 years from the time defoliation becomes evident, and causes the sudden collapse of these infestations. Evidence suggests that weather conditions are important in the initiation and spread of a fungal epizootic. High humidity, moderate rainfall, and temperature in the 60°F to 70°F range appear optimal.

Although the two fungal diseases, either alone or in combination with parasitic insects, are capable of causing the collapse of looper outbreaks; they failed to do so before intolerable tree mortality occurred. Although, they cannot be expected to provide complete control of the hemlock looper, improvement in their use may greatly reduce the need for applying insecticides and minimize losses during periods of extensive outbreaks. This possibly prompted the initiation of experiments which have shown that the fungal disease can be transmitted from artificially infected larvae to healthy larvae in the field. The technique appears promising as a control method but its application depends on developing an economic method of mass producing spores. If infection is started artificially, it would be most useful if pathogens were applied to looper larvae during early instars, and before infestations reached epidemic levels.

LITERATURE CITED

Campbell, D.K. 1946. Western hemlock looper (Lambdina fiscellaria lugubrosa (Hulst))parasitism. Bi-monthly Prog. Rpt. 2(6): 3-4. Nov.-Dec.

Carolin, V.M. and R.R. Lejeune. 1967. Western hemlock looper, Lambdina fiscellaria lugubrosa Hulst. In Important forest insects and diseases of mutual concern to Canada, the United States and Mexico. (ed) A.G. Davidson and R.M. Prentice, Department of Forestry and Rural Development, Canada. pp. 123-125.

Carroll, W.J. 1956. History of the hemlock looper, Lambdina fiscellaria fiscellaria (Guen.), (Lepidoptera: Geometridae) in Newfoundland, and notes on its biology. Can. Ent. 88(10): 587-599.

Carroll, W.J. and W.E. Waters. 1967. The eastern hemlock looper Lambdina fiscellaria fiscellaria (Guen.). In Important forest insects and diseases of mutual concern to Canada, the United States and Mexico. (ed) A.G. Davidson and R.M. Prentice, Department of Forestry and Rural Development, Canada. pp. 121-122.

Chrystal, R.N. 1916. Forest insect investigation in Stanley Park, Vancouver, British Columbia. The Agricultural Gazette of Canada 3(1): 794-798.

Clark, R.C., I.S. Otvos, and K.E. Pardy. 1973. Biological agents introduced and released in Newfoundland for the control of forest insect pests. Environ. Canada, Can. For. Serv., Inf. Rpt. N-X-96. 42 p.

Cunningham, J.C. 1970a. The effect of storage on the nuclear polyhedrosis virus of the eastern hemlock looper, Lambdina fiscellaria fiscellaria (Lepidoptera: Geometridae). J. Invert. Path. 16: 352-356.

Cunningham, J.C. 1970b. Pathogenicity tests of nuclear polyhedrosis viruses infecting the eastern hemlock looper, Lambdina fiscellaria fiscellaria (Lepidoptera: Geometridae). Can. Ent. 102(2): 1534-1539.

de Gryse, J.J. and K. Schedl. 1934. An account of the eastern hemlock looper, Ellopia fiscellaria Gn., on hemlock, with notes on allied species Sci. Agr. 14: 523-539.

Doan, C.C. 1969. Trans-ovum transmission of a nuclear-polyhedrosis virus in the gypsy moth and the inducement of virus susceptibility. J. Invert. Path. 14: 193-210.

Fletcher, J. 1893. The Vancouver Island oak looper. Rpt. of Entomology and Botany in Canada, Exp. Farms Rpt., pp. 175-177.

Fracker, S.B. and A.A. Granovsky. 1927. The control of hemlock looper by airplane dusting. J. econ. Ent. 20: 287-294.

Hopping, G.R. 1934. An account of the western hemlock looper, Ellopia somniaria Hulst, on conifers in British Columbia. Sci. Agr. 15: 12-24.

Houser, J.S. 1927. Ellopia athasaria Walker, a looper attacking hemlock. J. econ. Ent. 20: 299-301.

McGugan, B.M. and H.C. Coppel. 1962. Biological control of forest insects, 1910 - 1958. In A review of biological control attempts against insects and weeds in Canada. Tech. Comm. Commonw. Inst. Bio. Contr. 2: 35-127.

Morris, O.N. 1962. Quantitative infectivity studies on the nuclear polyhedrosis of the western oak looper, Lambdina fiscellaria somniaria (Hulst). J. Insect. Path. 4: 207-215.

Muldrew, J.A. 1953. A natural immunity of the larch sawfly (Pristiphora erichsonii (Htg.)) to the introduced parasite, Mesoleius tenthredinis Morley, in Manitoba and Saskatchewan. Can. J. Zool. 31: 313-332.

Otvos, I.S. 1973. A method for rearing overwintering larvae of Winthemia occidentis (Diptera: Tachinidae), a parasite of the eastern hemlock looper. Can. Ent. 105: 581-582.

Otvos, I.S. and M.E. Taylor. 1970. Avian predators of the eastern hemlock looper in Newfoundland. Bi-monthly Res. Notes 26(3): 22.

Otvos, I.S., R.C. Clark and L.J. Clarke. 1971. The hemlock looper in Newfoundland; the outbreak, 1966 to 1971; and aerial spraying, 1968 and 1969. Environ. Canada, Can. For. Serv., Inf. Rpt. N-X-68, 62 p.

Otvos, I.S. and D.G. Bryant. 1972. An extraction method for rapid sampling of eastern hemlock looper eggs, Lambdina fiscellaria fiscellaria (Lepidoptera: Geometridae). Can. Ent. 104: 1511-1514.

Reeks, W.A., W.J. Carroll, and R.D. Sheppard. 1949. Forest insects in Newfoundland in 1949. In Ann. Rpt. Nfld. For. Prot. Assoc. pp. 53-68.

Sager, S.M. 1957. A virus disease of the western hemlock looper, Lambdina fiscellaria lugubrosa (Hulst) (Lepidoptera: Geometridae). Can. J. Microbiol. 3: 799-802.

Salt, G. 1934. Experimental studies in parasitism. II. Superparasitism. Proc. Roy. Soc. London Ser. B. Biol. Sci. 114: 455-476.

Sheppard, R.D. 1950. Forest Entomology in Newfoundland in 1950. In Ann. Rpt. Nfld. For. Prot. Assoc. pp. 47-59.

Smith, H.S. 1916. An attempt to redefine the host relationships exhibited by entomophagous insects. J. econ. Ent. 9: 477-486.

Torgersen, T.R. 1971. Parasites of the western hemlock looper, Lambdina fiscellaria lugubrosa (Hulst), in southeast Alaska. The Pan-Pacif. Ent. 47: 215-219.

Torgersen, T.R. and B.H. Baker. 1967. The occurrence of the hemlock looper (Lambdina fiscellaria (Guenée) (Lepidoptera: Geometridae)) in southeast Alaska, with notes on its biology. Forest Serv. Res. Note PNW-61, 6 p.

Watson, E.B. 1934. An account of the eastern hemlock looper, Ellopia fiscellaria Gn., on balsam fir. Sci. Agr. 14: 669-678.

APPENDIX I

List of birds collected from 1969 to 1971 during a study of the eastern hemlock looper in Newfoundland[1]

SPECIES	1969 coll.	1969 with looper	1970 coll.	1970 with looper	1971 coll.	1971 with looper
Picidae						
Dendrocopos pubescens (Linnaeus) (Downy woodpecker)	2	0	0	0	0	0
Dendrocopos villosus (Linnaeus) (Hairy woodpecker)	2	0	2	0	0	0
Picoides arcticus (Swainson) (Black-backed three-toed woodpecker)	1	0	0	0	0	0
Tyrannidae						
Empidonax flaviventris (Baird & Baird) (Yellow-bellied flycatcher)	3	3	2	1	1	1
Empidonax minimus (Baird & Baird) (Least flycatcher)	0	0	2	2	0	0
Nuttallornis borealis (Swainson) (Olive-sided flycatcher)	0	0	2	0	0	0
Corvidae						
Perisoreus canadensis (Linnaeus) (Gray jay)	4	1	3	1	0	0
Paridae						
Parus atricapillus Linnaeus (Black-capped chichadee)	8	8	5	4	8	6
Parus hudsonicus Forster (Boreal chickadee)	1	1	1	1	6	6
Sittidae						
Sitta canadensis Linnaeus (Red-breasted nuthatch)	2	0	0	0	2	0
Turdidae						
Turdus migratorius Linnaeus (American robin)	2	0	3	1	0	0
Hylocichla guttata (Pallas) (Hermit thrush)	2	2	0	0	1	1

APPENDIX I - Continued.

SPECIES	1969 coll.	1969 with looper	1970 coll.	1970 with looper	1971 coll.	1971 with looper
	Number of birds					
Hylocichla ustulata (Nuttall) (Swainson's thrush)	0	0	5	3	0	0
Silviidae						
Regulus calendula (Linnaeus) (Ruby-crowned kinglet)	1	0	1	0	0	0
Parulidae						
Mniotilta varia (Linnaeus) (Black-and-white warbler)	2	2	1	1	2	2
Dendroica coronata (Linnaeus) (Myrtle warbler)	2	1	0	0	0	0
Dendroica petechia (Linnaeus) (Yellow warbler)	0	0	2	1	0	0
Dendroica striata (Forster) (Blackpoll warbler)	1	1	2	2	0	0
Dendroica virens (Gmelin) (Black-throated green warbler)	3	3	4	3	0	0
Oporornis formosus (Wilson) (Kentucky warbler)	0	0	1	0	0	0
Oporornis philadelphia (Wilson) (Mourning warbler)	1	1	1	1	0	0
Vermivora peregrina (Wilson) (Tennessee warbler)	1	1	1	0	0	0
Seiurus noveboracensis (Gmelin) (Northern waterthrush)	1	1	1	0	2	2
Geothlypis trichas (Linnaeus) (Common yellowthroat)	1	1	0	0	0	0
Fringillidae						
Capodacus purpureus (Gmelin) (Purple finch)	2	2	1	0	0	0
Pinicola enucleator (Linnaeus) (Pine grosbeak)	11	11	7	5	0	0

APPENDIX I - Concluded.

SPECIES	1969 coll.	1969 with looper	1970 coll.	1970 with looper	1971 coll.	1971 with looper
	Number of birds					
Melospiza georgiana (Latham) (Swamp sparrow)	0	0	2	0	0	0
Zonotrichia albicollis (Gmelin) (White-throated sparrow)	7	4	4	3	1	1
TOTAL	69	43	48	25	23	19

[1]Names of birds taken from Godfrey, W.E. 1966. The birds of Canada. Queen's Printer, Ottawa. 428 p.