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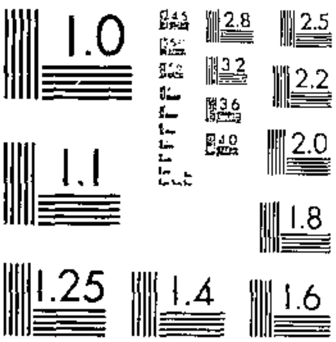

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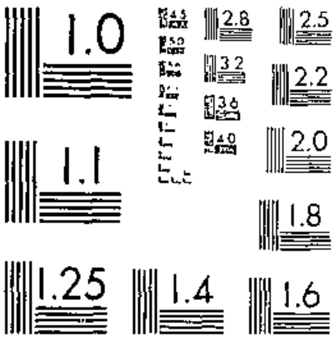

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APANTELES SOLITARIUS (RATZEBURG), AN INTRODUCED BRACONID PARASITE OF THE SATIN MOTH

By D. L. PARKER,[1] *junior entomologist, Division of Forest Insects, Bureau of Entomology and Plant Quarantine*

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INTRODUCTION

Apanteles solitarius (Ratzeburg)[2] is a solitary, internal parasite of the satin moth (*Stilpnotia salicis* L.). The satin moth, a pest of poplar and willow trees, was first discovered in the United States in 1920 just north of Boston, Mass. About a month later it was found in British Columbia, and in 1922 in the State of Washington. Since 1920 this insect has spread rapidly in the New England States, and a portion of this region is now under quarantine on account of it (fig. 1). The staff of the Budapest, Hungary, laboratory of the Bureau of Entomology, United States Department of Agriculture, made observations at areas in central Europe infested with the satin moth with the intention of obtaining for liberation in New England such primary parasites as attack it there but were not established in the United States. *A. solitarius* seemed to be generally distributed throughout central Europe wherever the satin moth was observed, and apparently was a valuable factor in its

[1] The writer is indebted to C. W. Collins, in charge of the Bureau of Entomology and Plant Quarantine laboratory at Melrose Highlands, Mass., for his cooperation in these studies. Acknowledgment is made to those members of the staff who worked on these experiments, especially C. F. W. Muesebeck and P. B. Dowden, who supervised these activities at different periods. Mr. Muesebeck also determined the adults that were reared during the crossbreeding experiments.

[2] Order Hymenoptera, superfamily Ichneumonoidea, family Braconidae.

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control (*1, pp. 8–9*).[3] The first shipment of parasite cocoons to this country was made in the summer of 1927, primarily as an experiment to determine the advisability of sending the parasite in the cocoon stage. Upon receipt of the cocoons at the Melrose Highlands, Mass.,

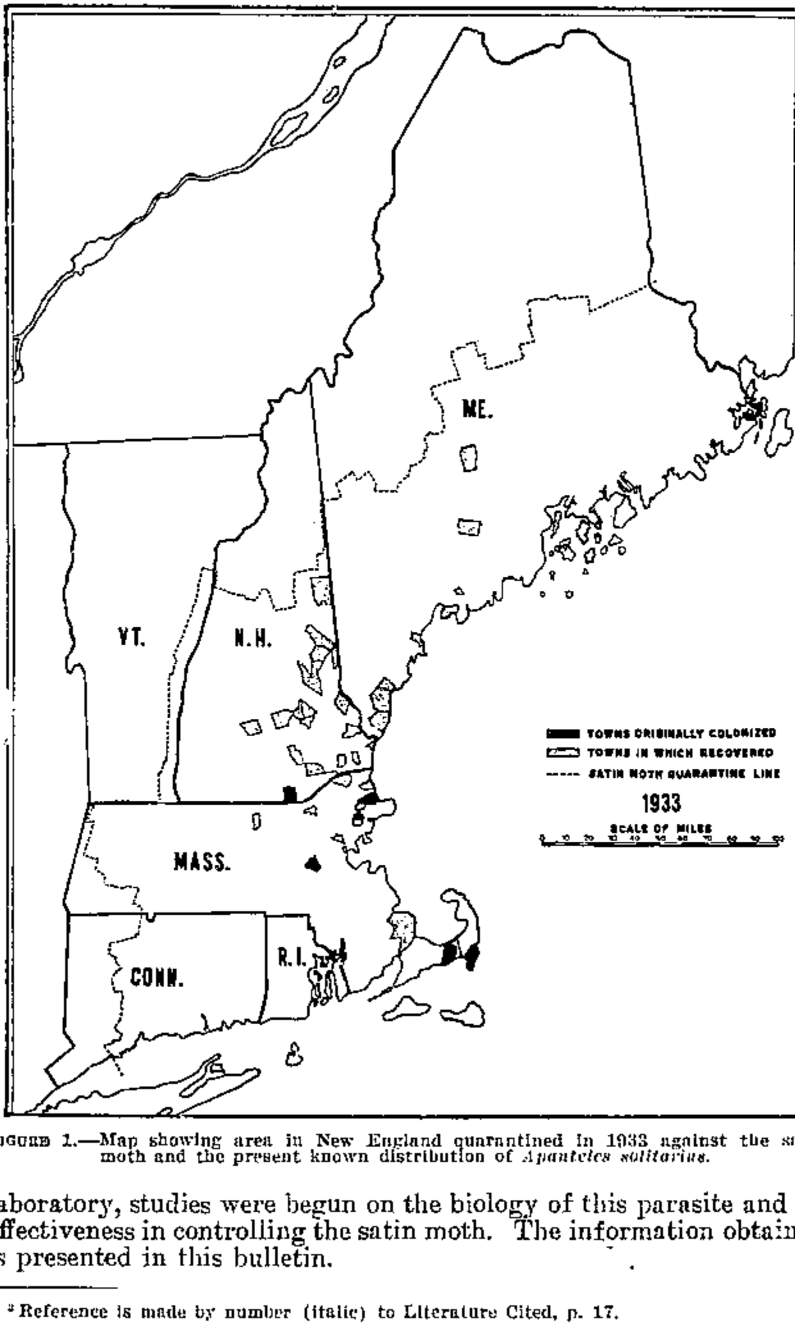

FIGURE 1.—Map showing area in New England quarantined in 1933 against the satin moth and the present known distribution of *Apanteles solitarius*.

laboratory, studies were begun on the biology of this parasite and its effectiveness in controlling the satin moth. The information obtained is presented in this bulletin.

[3] Reference is made by number (italic) to Literature Cited, p. 17.

IMPORTATION AND COLONIZATION

In the shipment of *Apanteles solitarius* received in 1927 there were 105 cocoons. A total of 36 male and 19 female adults issued from these cocoons. The species became established quickly, and there were no additional shipments of *solitarius* material until 1932, when 542 cocoons were included in shipments of other parasites. All the adults colonized prior to 1932 were bred from the females received in the original shipment. Since 1932 very few cocoons have been received.

From 1927 to 1932 adults of this species were liberated in 5 towns in Massachusetts and 1 town in New Hampshire, and one lot of adults was shipped to Kent, Wash. With the exception of one colony in Massachusetts, which was placed in an area infested with the white-marked tussock moth (*Hemerocampa leucostigma* S. and A.), all the liberations were made in localities infested with the satin moth. Adults were liberated at two periods in the life cycle of the satin moth, at the time the larvae were feeding after leaving their hibernacula and when the larvae were hatching from the eggs during the summer.

Colonization was also effected by the liberation of first- and second-instar larvae of the satin moth that had been parasitized in the laboratory. Parasitized larvae were liberated in 2 towns in Massachusetts, in 1 of which adults were also liberated. It was believed that, by placing the parasitized larvae in the field just prior to hibernation, most of the parasites would issue at about the same time and be concentrated in the infested area, and that this would lessen the work of rearing the adult parasites.

This method can be used to colonize the species, but it is doubtful if it is so satisfactory as the liberation of adults. Observations made at one infested area where parasitized larvae had been liberated indicated that very few of the larvae had survived the winter. The base of one limb of a willow tree upon which parasitized larvae had been placed was treated with a sticky tree-banding material to force the larvae to remain on this small section of the tree while feeding, and also to hibernate there instead of on the trunk. When the limb was examined in the spring, few larvae were present.

In 1933 the Canadian Department of Agriculture sent two representatives to the Melrose Highlands laboratory to obtain *Apanteles solitarius* material for colonization in areas infested with the satin moth in Canada. These men, with assistants, collected the parasite cocoons, held them in a cool place, and transported them to the laboratory in Canada, where the adults were allowed to issue. These adults were then sent to various points in Canada for liberation. According to subsequent correspondence from Canada, the species has been recovered from Sussex, Moncton, and Sackville in New Brunswick, and from Amherst in Nova Scotia. In British Columbia the species has been recovered over a fairly large area in the Fraser River Valley around Nicomen, the liberation point.

DISTRIBUTION

In order to study the occurrence and spread of *Apanteles solitarius*, hibernating satin moth larvae were collected in towns over an area extending from Rhode Island to Maine through Massachusetts and New Hampshire.

The year following the first liberations the species was recovered in four localities in Massachusetts, New Hampshire, and Maine. The parasite spread rather rapidly. One year after it was liberated at Nashua, N. H., it was recovered at Manchester, N. H., about 15 miles away. The second year after liberation it appeared in collections from 8 towns, 4 in Massachusetts and 4 in New Hampshire. The parasite has continued to spread and is now apparently distributed throughout the area in New England that is infested by the satin moth. The towns in which recovery collections have shown establishment of this parasite are shown on the map in figure 1, but without doubt the parasite is present in many other towns.

HOST RELATIONS

Apanteles solitarius is capable of reproducing on several lepidopterous hosts other than the satin moth. At the laboratory many adults were reared from larvae of the gypsy moth (*Porthetria dispar* L.). This host was used in the rearing experiments because it was easier to collect the gypsy moth eggs in the spring and rear the larvae for parasitization than to collect small satin moth larvae in the field. *A. solitarius* has also been reared successfully on the rusty tussock moth (*Notolophus antiqua* L.), the white-marked tussock moth (*Hemerocampa leucostigma* S. and A.), and the brown-tail moth (*Nygmia phaeorrhoca* Don.). Attempts were made to overwinter the species in the small larvae of *N. phaeorrhoea*, *Euphydryas phaëton* Drury, *Basilarchia archippus* Cramer, and *Olene* sp., but without success.

There have been no field recoveries of *Apanteles solitarius* from these hosts, but it would be surprising if it did not attack gypsy moth larvae when they are present in the same locality as the satin moth.

METHOD OF LABORATORY BREEDING

It was comparatively easy to breed *Apanteles solitarius* in the laboratory. The method that appeared to be the most satisfactory and efficient for bringing about reproduction of the species for liberation purposes will be described.

Parasitization of host larvae was accomplished in glass vials (8 by 2 inches). From 3 to 5 mated females were placed in each vial and a larva was introduced on a fine camel's-hair brush. As soon as a female had oviposited within the larva, it was removed and another one was introduced. With 35 to 50 mated females, one man could subject 700 to 1,000 larvae to parasitization in a day. The parasitized larvae were placed in lots of 200 in paraffined paper trays the sides of which were banded with a sticky tree-banding material to prevent the escape of the larvae. The larvae in the trays were fed with oak foliage until the cocoons of the parasite were formed, and then the cocoons were removed to glass vials (4 by 1 inches) and kept there until the adults issued. A number of adults of each sex were placed in cages and held for later mating. These cages (9½ by 6⅜ by 4½ inches) had sliding glass tops and a hole at one end through which a sponge saturated with a solution of honey and water could be introduced. The mated females used in reproduction experiments were kept in glass vials (8 by 2 inches) in a dark, cool place when they were not being used for parasitization of larvae. The adults that were colonized were held in wooden boxes or small cloth cages in a cool place until time of liberation.

THE ADULT

DISTINGUISHING CHARACTERS

Apanteles solitarius (fig. 2) was first described by Ratzeburg (*7, p. 73*) as *Microgaster solitarius* in 1844. This species is closely re-

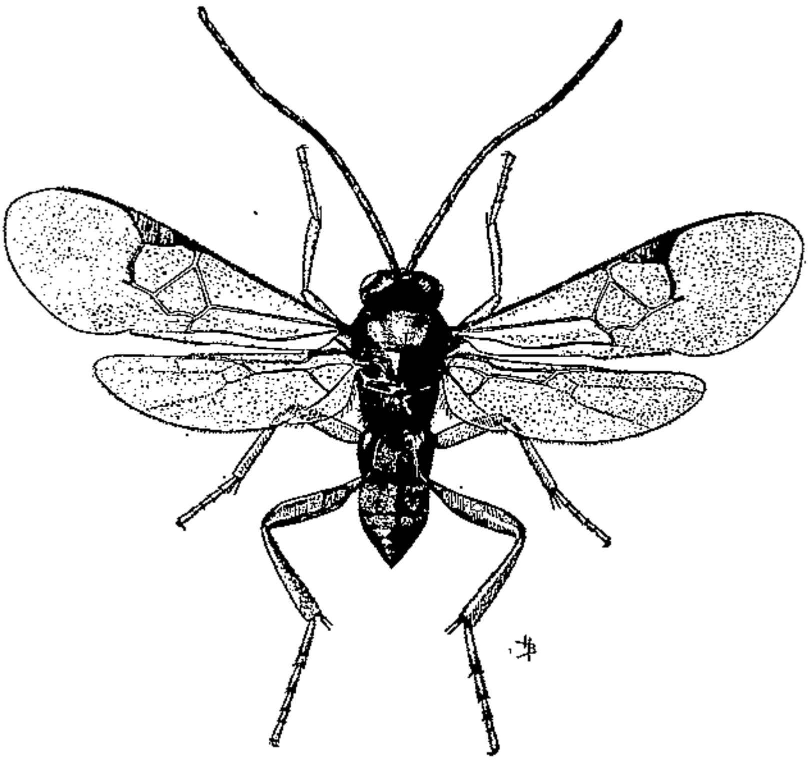

FIGURE 2.—Adult female of *Apanteles solitarius*. × 15.

lated to *A. melanoscelus* (Ratz.), and there has been some confusion regarding the two species, but the differences are sufficiently marked to permit their separation. A redescription of *melanoscelus* was presented by Crossman (*3, p. 3*) in 1922. The main difference between *solitarius* and *melanoscelus* is in the sculpture of the abdominal tergites. In *solitarius* the sculpture of the third tergite is usually more extensive and stronger, at least medially. In *solitarius* the second tergite is usually more extensively sculptured; in *melanoscelus* the sides of the second tergite, especially apically, are mostly smooth.

MATING

The chief difficulty encountered in breeding *Apanteles solitarius* was in getting the sexes to mate. Many attempts were made to induce mating in cages and vials of various types and sizes under varied conditions of light and temperature with adults of different ages. The conditions most suitable for normal mating seemed to be a temperature of 65° to 70° F. and a somewhat subdued light. Even under these conditions it was a long and tedious task to obtain 10 or 15 mated females. Finally a procedure was devised by which it was possible to obtain enough mated females for propagation. The virgin females were starved for 8 to 10 hours and then about 10 to 15 were placed in a cage with 25 males that had had access to food. A wooden-frame cage, 9½ by 6⅜ by 4½ inches, covered with cloth except for a sliding glass front, seemed more suitable than larger cages. A little honey-and-water solution was spread on the cloth back of the mating cage, and the females, being very hungry, fed there eagerly, which allowed the males to mate with them successfully. The possible effect of such mating was unknown, but it proved successful when judged by the sex ratio of the adults reared in the experiment. When such a method is used, it is important to keep the females in a dark place while they are being starved, for too much activity during this period of 8 to 10 hours will exhaust them and many will die.

The position taken during mating is normal to species of *Apanteles*, and the act is completed in less than a minute.

OVIPOSITION

The adults of *Apanteles solitarius* are ready to oviposit within a few hours after they issue from the cocoons. The act of oviposition is not one of slow and studied attack, but rather a nervous thrust. When the female senses the presence of a suitable host larva, she approaches it rapidly and very quickly inserts the ovipositor with a thrust and immediately leaves the larva. The female may oviposit in any part of the caterpillar, and eggs deposited in any part of the body will develop.

REPRODUCTIVE CAPACITY

In order to ascertain the reproductive capacity of this species, it was decided to isolate 5 females and allow them to attack a few larvae each day. From 5 to 10 larvae were placed with each female during the day and removed late the same day. They were dissected the following day, for it was found that the eggs of the parasite enlarged, and were therefore more readily seen, after 24 hours.

The females issued on June 13 and began to oviposit June 14. They oviposited every day for at least 13 days, and 1 female oviposited for 20 days. The number of eggs deposited ranged from 311 to 516, with an average of 402. The largest number of eggs laid by 1 female in 1 day was 53.

PARTHENOGENESIS

Unfertilized females of *Apanteles solitarius*, like many other parasitic Hymenoptera, deposit eggs that develop to male adults.

LONGEVITY

No experiments were conducted with the sole purpose of determining the length of life of adults of *Apanteles solitarius*. During the work on reproduction it was determined that the adults would live only a short time without food. Adults that had no food from late afternoon through the night were dead the next morning. Adults fed a solution of honey and water and held in a dark, cool room lived fairly long. In one lot of adults the peak of issuance occurred from May 6 to 9, and on May 31, 1,150 adults were alive out of an original 1,407. Another lot of 2,509 adults that issued from June 14 to 27, with the peak of issuance from June 17 to 18, was reduced in numbers to 1,389 on July 21, nearly a month after the last adult issued. Some of the deaths in the latter lot may be attributed to escaping gas in one of the insectaries. It is safe to say that the average length of life of these adults is from 3 to 4 weeks, and that the females live longer than the males.

THE EGG

The egg of *Apanteles solitarius* (fig. 3) at the time of deposition measures 0.28 to 0.53 mm in length and 0.06 mm in width at the widest part. It increases in size very rapidly in the dissecting fluid, and should therefore be measured as soon as possible after deposition. It is almost transparent, rounded at the cephalic end, enlarged medially, and narrowed posteriorly to a small petiole. The surface is smooth.

FIGURE 3.—Egg of *Apanteles solitarius*. × 245.

The eggs of this species develop rather rapidly and change greatly in size and shape. At the end of 48 hours some eggs measured 0.52 to 0.55 mm in length and 0.22 to 0.24 mm in width and were much smaller near the cephalic end. At this time the embryo was plainly seen lying in a slightly curved position.

The incubation period varies according to the temperature. In warm weather, at the time of reproduction experiments with the second generation, hatching was observed 69 hours after oviposition. The average time required for hatching earlier in the season, in May, was about 1 week, and in June or later it was 3 or 4 days.

THE FIRST-INSTAR LARVA

The first-instar larva of *Apanteles solitarius* (fig. 4) averages 0.58 mm in length and 0.18 mm in width at the time of hatching. Immediately after hatching, the larva may be found floating free in any part of the body cavity, but it gradually works its way to the posterior half of the body, where it remains the rest of its larval life. The newly hatched larva has a nearly transparent body, which tapers slightly from the large squarish head to the caudal end, which bears the caudal horn and bladderlike dorsal anal vesicle. This anal vesicle may not be prominent immediately after hatching, but it is soon evaginated. The newly hatched larva consists of the head, 3 thoracic segments, and 8 distinct abdominal segments. The last segment really consists of 3 undifferentiated segments, which become distinguishable later in the development of the first instar. On the dorsum of the second and third thoracic segments and on the first 8 abdominal segments there are irregular rows of rather stout but colorless spines. There are usually 2 spines on the last 2 thoracic segments, and they increase in number on each abdominal segment toward the caudal segments, and there is an unbroken row of spines across the dorsum of the eighth abdominal segment. These spines are not figured in the drawing (fig. 4), because the larva is drawn as viewed ventrally.

The head of a first-instar larva, at the time of hatching, is about twice the width of the body. When the head is viewed laterally, the mouth opening is situated somewhat ventrally and the two labral processes extend downward over the mouth opening. When it is viewed ventrally, the mandibles (fig. 5, *A*) can be seen. They are comma shaped, sharply pointed, and measure 0.075 to 0.086 mm in length, or an average of 0.79 mm.

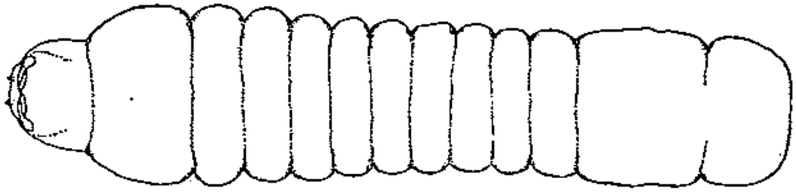

FIGURE 4.—First-instar larva (nearly full grown) of *Apanteles solitarius*, viewed ventrally. × 72.

Near the end of the first instar the appearance of the larva is greatly changed (fig. 4). The head is now small in comparison with the body, which is greatly enlarged from feeding, the anal vesicle is very large, and the caudal horn appears very small beneath the anal vesicle. There is still no visible tracheal system.

THE SECOND-INSTAR LARVA

The second-instar larva [4] differs considerably from the first. Its length increases from about 2 mm at the beginning to about 5 mm at the end of the instar. The body tapers from the large anal vesicle toward the head. The head has no apparent sclerotization, and only in the latter part of the instar is it possible to see the mandibles. The mandibles (fig. 5, *B*) are colorless, and careful adjustment of light is necessary to see them with a compound microscope. The base of the mandible is very broad, tapering to the blade, which has a bidentate tip. The mandible measures 0.07 to 0.08 mm in total length, and the blade is roughly one-half the total length. The labium and maxillae appear as fleshy lobes.

There are no open spiracles in the second instar, although the tracheal trunks can be seen during the latter part of the instar.

[4] Some authorities believe that species of *Apanteles* have more than three instars and that descriptions of the second instar include more than one instar.

THE THIRD-INSTAR LARVA

The *Apanteles* larva usually molts into the last instar just as it leaves the host and carries the anterior part of the exuvia partly out of the host as it leaves. The last-instar mandibles (fig. 5, *C*) are visible just before the molt. The exuvia can almost always be found projecting from the opening through which the larva has issued. The anal vesicle is retracted at the time of issuance from the host. The spinning of the cocoon starts immediately. Before issuing from the host the larva measures 6 to 7 mm in length, but after it has spun its cocoon it contracts to 3 to 4 mm.

During the early part of the last instar the shape of the larva greatly resembles that of the second instar, but just before issuance it assumes a shorter and plumper appearance, is tapered anteriorly, and bears fleshy lobes laterally on the first 8 abdominal segments. (Fig. 6.) The surface of the skin is minutely pebbled, and each of the first 12 segments of the body bears a ring of rather stout, sharp spines. The larva bears 8 pairs of open spiracles, 1 pair on the mesothoracic segment, and 1 pair on each of the first 7 abdominal segments.

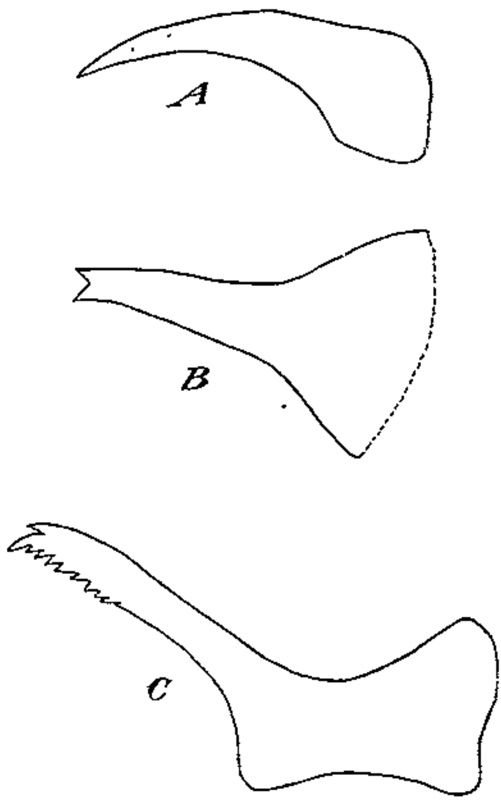

FIGURE 5.—Mandibles of larva of *Apanteles solitarius*: *A*, Of first-instar larva; *B*, of second-instar larva; *C*, of third-instar larva. × 590.

The head (fig. 7) presents a very different appearance from that of the previous instar. The buccal armature[5] is well sclerotized and mostly well defined. The labiostipital sclerome (*las*) encloses the labium (*la*) in a well-defined sclerotized border. The maxillary sclerome (*mas*) extends laterally and posteriorly from the side of the labiostipital sclerome toward the base of the hypostoma (*hy*). The hypostoma extends from the posterior part of the head at the base of the postocciput anteriorly toward the mouth opening. Beyond the junction of the hypostoma and the stipital sclerome (*sts*)

[5] The terminology used in the description of the larval head is that used by Vance and Smith in their paper on the larval head of parasitic Hymenoptera (8).

the hypostoma becomes rather indistinct, the pleurostoma is scarcely indicated, and the epistoma is not apparent. The ligular selerome (*lis*) is faintly seen ventrad of the silk duct (*sdo*).

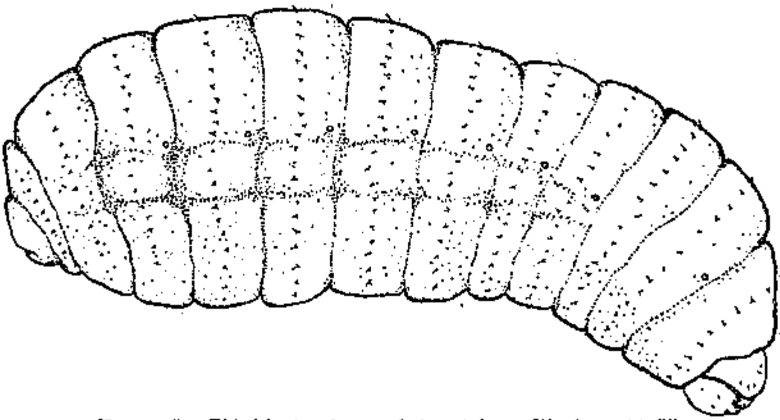

FIGURE 6.—Third-instar larva of *Apanteles solitarius*. × 33.

Dorsally above the mouth opening, situated on the labrum (*lm*), are 2 brownish pigmented areas, each enclosing 3 light-colored areas which may be sensory in function. Above these are 2 irregular

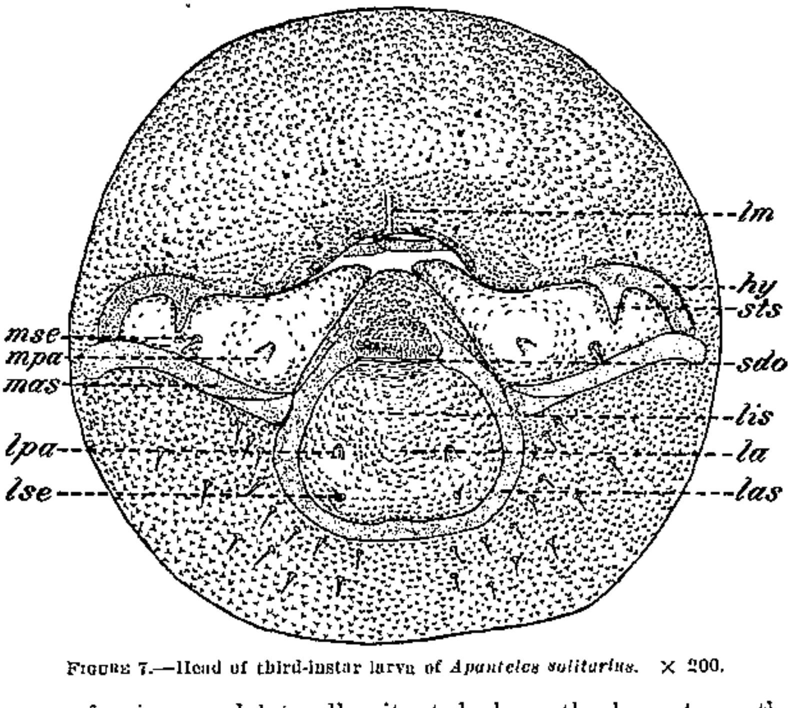

FIGURE 7.—Head of third-instar larva of *Apanteles solitarius*. × 200.

groups of spines, and laterally situated above the hypostoma there are other spines. The spines in these groups vary in number on different specimens, and even on the same individual the number on one side of the head may differ from the number on the other side. The raised fleshy maxillae bear rudimentary maxillary palpi (*mpa*) and setae (*mse*). The labium bears 2 rudimentary palpi (*lpa*) and 2 setae (*lse*).

The labium, the maxillae, and the remaining dorsal region of the head are covered with minute papillae which give this surface a pebbled appearance. The remainder of the head ventrad of the labiostipital sclerome and the maxillary scleromes is covered with minute spines. There is a group of large spines in this area, varying in number and apparently not arranged in a definite pattern.

The mandible of the third-instar larva of *Apanteles solitarius* (fig. 5, *C*) has a rather broad base and a slender, elongate shank terminating in two teeth and bearing several rather stout teeth beneath. These mandibles measure 0.12 mm in length.

PREPUPA AND PUPA

The hibernating larvae of *Apanteles solitarius* within a cocoon remains throughout the winter as a prepupal larva, pupating late in April.

Within the cocoon that produces an adult the same season the following changes occur. In about 2 days after completing its cocoon, the larva pupates and casts its larval skin, which is found at the posterior end of the cocoon with the previously voided meconium. The pupa is white at first, but it gradually becomes black. The pupal skin is cast and the adult escapes after cutting the circular cap at the end of the cocoon.

CROSSBREEDING EXPERIMENTS

Because of the morphological similarity between *Apanteles solitarius* and *A. melanoscelus*, several crossbreeding experiments were conducted. Females of each species were mated with males of the other, and the resulting progeny were carried through two generations. The adults reared in these experiments were classified by C. F. W. Muesebeck, of the Division of Insect Identification, as follows: (1) Typically *A. melanoscelus*, (2) typically *A. solitarius*, (3) indeterminable.

The results have been summarized in table 1. It will be seen that the F_1 generation in both cases tended to resemble the female parent, and that this tendency was stronger in the F_2 generation. The F_1 females used in producing the F_2 generation were all mated. Apparently these species, when crossed, tend to remain as distinct species instead of converging and producing a blend of the characters. One would expect that, if these species should crossbreed in nature, the results would be similar and the identity of neither species would be lost.

TABLE 1.—*Classification of adults reared in crossbreeding experiments between Apanteles melanoscelus and A. solitarius*

Parents	Number of individuals reared in—					
	F_1 generation			F_2 generation		
	A. melanoscelus	*A. solitarius*	Indeterminable	*A. melanoscelus*	*A. solitarius*	Indeterminable
Female *A. melanoscelus* × male *A. solitarius*	124	41	61	150	24	58
Female *A. solitarius* × male *A. melanoscelus*	33	120	50	28	207	68

SEASONAL HISTORY

The seasonal history of *Apanteles solitarius* is somewhat involved, because the species may pass the winter in either of two forms. It may overwinter as a prepupal larva in its cocoon or as a first-instar larva within the host.

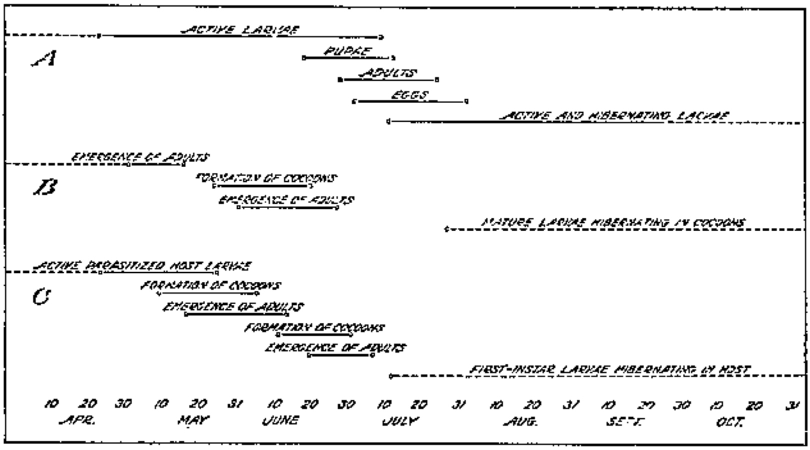

FIGURE 8.—Chart representing seasonal histories of: *A*, Satin moth; *B*, *Apanteles solitarius* overwintering in cocoon; *C*, *A. solitarius* overwintering as first-instar larva within satin moth larva.

The seasonal histories of the two hibernating forms of *Apanteles solitarius* and also that of the host are portrayed in figure 8. The information concerning the seasonal history of the host was taken from that given by Burgess and Crossman (*2, pp. 7–11*). The seasonal history of the parasite was compiled from laboratory rearing records and applied to the average conditions that might reasonably be expected in the field. The life of the adults might be longer or shorter than that encountered in the laboratory, and the period represented on the charts is a reasonable expectation of the length of life in the field.

The larvae of the satin moth begin to leave their hibernacula late in April, and this exodus continues until the latter part of May (fig. 8, *A*). The peak of emergence is early in May, and active growing larvae are present in the field until early in July. Pupation starts during the last half of June and adults appear about the last of June, with the peak of emergence in July. By the first of August egg laying is practically over. The eggs hatch in about 12 to 15 days, and the larvae feed during two instars and molt into the third instar in the hibernacula.

The *Apanteles solitarius* adults that issue from cocoons formed the previous fall appear during the first part of May, the majority during the first week (fig. 8, *B*). These adults attack the larvae that are coming out of hibernation, and cocoons are formed at this time of year in about 23 to 28 days after egg deposition and the resulting adults issue from 7 to 10 days later. Some of the adults of this first summer generation live until the *Stilpnotia salicis* eggs hatch and then attack the first-instar larvae. Some of the *A. solitarius* larvae within these parasitized hosts do not develop beyond the first instar and pass the winter in this instar, resuming activity and growth when the host larvae begin feeding in the spring. Other parasite larvae complete their growth, issue, and spin cocoons, and some of these cocoons produce adults the same season while others do not until the following spring.

The parasite larvae that remain within the host during the winter resume their activity when the host larvae commence their spring feeding (fig. 8, *C*). They usually issue and form their cocoons while the host larvae are in molting webs at the end of the fourth instar. These cocoons can be seen beneath the surface of the thin molting webs in the fissures of the bark. The adults appear about the middle of May and attack the small host larvae that are emerging rather late from their hibernacula. It was found in the laboratory experiments that unparasitized host larvae remained in hibernation later in the spring than those containing hibernating larvae of *A. solitarius*. The cocoons of this generation of the parasite are formed in 13 to 20 days after egg deposition. From some of them adults issue 7 to 10 days later, but others do not produce adult parasites until the following spring. Those adults that emerge shortly after formation of the cocoons attack the small larvae that are hatching in the field during the second week in July. The life history from this time on is similar to that for the group produced by adults from overwintering cocoons.

In laboratory experiments it was observed that a small number of cocoons of the first generation did not produce adults until the following spring.

From a study of the seasonal history it is evident that *A. solitarius* is well suited to its host. There is little time when there are no adults present, although they do not attack the large larvae so readily as they do the small larvae. The lengthened period during which the host larvae leave hibernation and develop is a distinct aid to the parasite.

EFFECTIVENESS

Hibernating satin moth larvae that have been collected since *Apanteles solitarius* was liberated have been dissected both to ascertain if the species was established in the locality where the collection was made and to determine its effectiveness in reducing the numbers of hibernating hosts. The fact that 1,942 larvae collected in different localities prior to the liberation of *solitarius* produced only 3 cases of parasitization by *Apanteles* seemed to justify the determination of any *Apanteles* larvae that were found after the liberations as those of *solitarius*.

The percentage of parasitization has varied considerably in different localities during the same year, and from year to year in the same locality. In large collections it has ranged from just a trace to 30 percent, and in many small collections of less than 100 larvae the percentages have run higher. In 1932 the infestations at most of these collection points were very low in intensity, which made observation and collection very difficult. These observations showed clearly that the parasite was able to persist and do rather effective work. In 15 collections of from 3 to 62 larvae each the percentage of parasitization ranged from zero in 1 collection to 100 in 3 other collections.

Late in October 1933 several satin moth infestations were examined in 11 locations in New Hampshire, 3 in Maine, and 1 in Massachusetts, to determine the effectiveness of *A. solitarius* in reducing the numbers of hibernating *salicis* larvae. The hibernacula were examined and classified, the living larvae collected for dissection, and also the *solitarius* cocoons formed from hibernating *salicis* larvae. By spending a uniform period, 1½ hours, at each location, it was believed that a rough indication of the degree of infestation would be obtained.

The information obtained is presented in table 2.

TABLE 2.—*Results of examination of satin moth hibernacula in 15 towns in New Hampshire, Maine, and Massachusetts in 1933*

Location of infestation	Hibernacula examined	Unparasitized larvae	Larvae parasitized by *Apanteles solitarius*	Larvae parasitized by other species	Larvae dead from unknown cause
	Number	*Percent*	*Percent*	*Percent*	*Percent*
New Hampshire:					
Henniker	112	21.4	65.2	4.5	8.9
Concord	190	41.6	24.2	2.1	32.1
North Chichester	242	10.0	61.6	2.9	10.5
Pittsfield	214	29.0	51.4	4.7	14.9
Alton	129	26.4	46.5	7.8	19.3
Wolfeboro	146	10.3	50.0	2.0	37.7
West Alton	193	20.7	56.5	0.0	22.8
Ossipee	306	20.6	66.7	2.6	10.1
Union	234	56.8	31.6	3.0	8.6
Rochester	212	21.2	58.0	2.4	18.4
Rye	184	33.2	42.9	2.2	21.7
Maine:					
Portland	240	17.1	63.0	2.0	17.9
Ogunquit	191	34.5	44.0	1.6	19.9
Kennebunk	219	26.4	48.4	1.0	24.2
Massachusetts:					
South Yarmouth	193	40.4	14.5	7.3	37.8

It was impossible to determine what percentage of the original population reached the hibernating stage. There is, no doubt, some mortality during the first instar and during the portion of the second instar spent in active feeding before the hibernaculum is formed. Therefore the data presented show the degree of parasitization of that portion of the original population which entered hibernation.

The figures in the table demonstrate that *A. solitarius* has reduced the numbers of *salicis* larvae in hibernation 14.5 to 66.7 percent in different localities and that in 12 of the 15 towns it effected a parasitization greater than 40 percent. If the intensity of an infestation is judged by the number of hibernacula examined in 1½ hours, it is evident that *solitarius* was very effective in both the lightest and the heaviest infestations.

There will be a further reduction of the host larvae in the spring when they leave their hibernacula and begin feeding, because they are available for attack by *Apanteles* adults appearing at that time.

The writer considers that *Apanteles solitarius* is an effective agent in the reduction of a satin moth infestation, because it is capable (1) of producing a rather high percentage of parasitization, (2) of maintaining itself when the infestation is low in intensity, and (3) of rapid spread. The fact that hibernation occurs in two different forms and that there are several generations a year also increases the effectiveness of the species.

LIMITING FACTORS

Larvae of the genus *Apanteles* in cocoons are subject to considerable attack by other parasites. This subject has been well discussed by Muesebeck and Dohanian (*4*) in the case of *A. melanoscelus* Ratz. According to Proper (*6*), *A. solitarius* is attacked by many of the species that attack *melanoscelus*, as its cocoons are present when these parasites are active. The fact that the species overwinters not only as a prepupa in its cocoon but also as an immature larva is a distinct advantage, for its survival does not depend entirely upon the successful overwintering of cocoons.

The larvae of *Eupteromalus nidulans* (Thomson), a parasite of the hibernating satin moth larvae, doubtless kill some first-instar *Apanteles solitarius* larvae in the hibernating hosts. According to Proper (*5, pp. 44–45*), the adults of *Eupteromalus* kill some satin moth larvae by feeding on the body fluids, and this would result in the destruction of the parasite larvae within such host larvae.

In a few infestations a mite, *Pediculoides* sp., possibly *ventricosus* Newport, was encountered feeding on the *Stilpnotia salicis* larvae and thus killing any *Apanteles solitarius* larvae that they might have contained. This mite is sometimes an effective agent in controlling the host, one infestation having shown 56 percent of the host larvae killed by it at the time of the examination, and there was time for considerable more activity before winter. Brown (*1, pp. 15, 16*) records one instance of the work of *Pediculoides ventricosus* Newport in an infestation of the satin moth in Budapest, Hungary, when it was impossible to find any living larvae of the satin moth in the spring following the first observation of the mite in the infestation. In such event, of course, all *solitarius* larvae present would be destroyed.

From the distribution of *Apanteles solitarius* in Europe there do not appear to be any climatic factors that would limit the distribution or effectiveness of *solitarius* where the host itself could survive.

SUMMARY

Apanteles solitarius (Ratzeburg) is a solitary, internal parasite of the satin moth, a pest of poplar and willow trees. The parasite was

introduced into the United States in 1927 and has been released in 5 towns in Massachusetts, 1 in New Hampshire, and in Kent, Wash. Recently the species has been introduced into Canada from material obtained in New England.

Apanteles solitarius has been reared in the laboratory on several lepidopterous hosts other than the satin moth, but there have been no field recoveries from these hosts. The species lends itself readily to propagation in the laboratory, and methods of doing this are presented. To induce mating was rather difficult, but this was accomplished satisfactorily by starving the females for 8 to 10 hours before introducing them into cages containing food and males. The females oviposit readily and are capable of depositing from 311 to 516 eggs, with an average of 402. The largest number laid by 1 female in 1 day was 53. Unmated females deposit eggs that produce male adults.

The newly deposited egg of *Apanteles solitarius* is nearly transparent, rounded at the cephalic end, enlarged medially, and narrowed posteriorly to a small petiole. The egg measures 0.28 to 0.33 mm, but increases greatly in size before hatching. Only three larval instars have been distinguished. Descriptions of the three instars are presented.

Crossbreeding experiments between *Apanteles solitarius* and *A. melanoscelus* indicate that if these two species crossbreed in nature the tendency will be for each species to retain its identity.

The species overwinters in two forms, as a prepupal larva within a cocoon and as a first-instar larva within the hibernating host. The adults from the overwintering cocoons emerge before those larvae that overwintered in the first instar form cocoons. These adults attack the host larvae coming from their hibernacula and produce cocoons late in May and early in June. The adults from these cocoons attack small larvae of the host, and from this attack some parasite larvae overwinter in the first instar, some cocoons are formed, and a small number of adults may issue. The adults from the overwintering larvae appear about the middle of May. They attack the feeding larvae of the host and produce a generation which in time attacks the very small larvae. The history from this point on corresponds with that for the group produced by adults from overwintering cocoons.

Collections from several towns indicate rapid spread of the parasite and that it is now apparently distributed over the territory in New England infested with the satin moth. From a study of the hibernating form of the host, it is shown that *Apanteles solitarius* effected a parasitization of 14.5 to 66.7 percent, and in 12 of the 15 towns in which observations were made the percentage of parasitization was greater than 40 percent.

The factors that are operating to reduce the effectiveness of *Apanteles solitarius* are the other parasites which attack the host and those parasites which normally attack cocoons of the genus *Apanteles*. There do not appear to be any climatic factors that would limit the effectiveness of this parasite where the host itself could survive.

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