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STUDIES ON PARASITES OF THE ORIENTAL FRUIT MOTH

II. MACROCENTRUS

PHILIP GARMAN and W. T. BRIGHAM

Connecticut
Agricultural Experiment Station
New Haven

CONNECTICUT AGRICULTURAL EXPERIMENT STATION

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CONTENTS

	Page
The Oriental fruit moth	74
Food requirements	76
Enemies	77
Effect of wintering and refrigeration on the larvae	78
Effect of refrigeration on the moths and eggs obtained from them	80
Effect of temperature on egg-laying activities of the fruit moth	81
Time of egg laying	83
Methods of hastening development and increasing emergence after bringing larvae from hibernation	84
Mass production	85
Sex ratio of reared moths	86
Other hosts and closely related species of Macrocentrus	87
The larval parasite, *Macrocentrus ancylivorus* Rohwer	88
Life history and habits	88
Comparison of life history of Macrocentrus and its host the Oriental fruit moth	93
Mating and oviposition of the parasite	94
Wintering habits	94
Length of oviposition or egg-laying period	96
Ratio and rate of increase	96
Effect of hibernation on sex ratio and ratio of increase	100
Sex ratio	100
Ratio of fruit moth eggs to number of Macrocentrus reared	102
Percentage parasitism in laboratory breeding	104
Enemies	104
Effect of insecticide dusts on Macrocentrus longevity	105
Important considerations in breeding work	106
Breeding schedule for rearing Macrocentrus employed at the Connecticut Experiment Station from 1931 to 1933	109
Macrocentrus parasites obtained in New Jersey in 1930 and 1931	110
Field liberations of Macrocentrus and observations on their effectiveness	111
Acknowledgments	114
Summary and conclusions	115
The Oriental fruit moth	115
The larval parasite, *Macrocentrus ancylivorus*	115
References	116

STUDIES ON PARASITES OF THE ORIENTAL FRUIT MOTH

II. MACROCENTRUS ANCYLIVORUS

PHILIP GARMAN AND W. T. BRIGHAM

In conjunction with production of Trichogramma for control of the Oriental fruit moth, the results of which have already been reported, field and laboratory work was begun in 1929 on the larval parasite, *Macrocentrus ancylivorus* Roh. (Figure 1). This parasite was known to occur in limited numbers in Connecticut and to have survived in the Barnes peach orchard in Wallingford since 1926. Because of its general scarcity in many

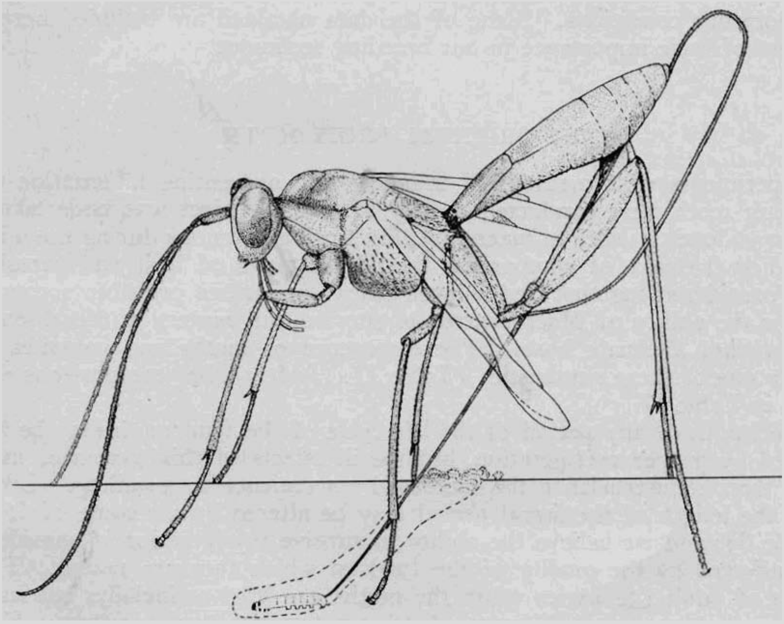

FIGURE 1. Side view of Macrocentrus female showing the method of depositing egg in the larvae of the Oriental fruit moth. The long antennae are apparently used to locate suitable larvae. (Greatly enlarged.)

Connecticut orchards and its entire absence from others, it was thought desirable to obtain them in considerable quantities for liberation. The strawberry leaf-roller[1] was first used as host for breeding but the Oriental fruit moth[2] was soon substituted because of serious difficulties in breeding leaf-

[1]*Ancylis comptana* Froel.
[2]*Grapholitha molesta* Busck.

rollers during the winter. The worst trouble was disease, which developed in the host larvae, and killed many before they could be utilized. Since this first attempt with the strawberry leaf-roller we have continued to use the Oriental fruit moth, but the difficulties preventing complete realization of our hopes with this host also seem to be numerous. Production of Macrocentrus on the same scale as Trichogramma is impossible at present, but we can see no reason for believing that Macrocentrus cannot be reared in much larger numbers than was possible during these studies.

Our work in the orchard, like that with Trichogramma, has been successful in some ways and unsuccessful in others. This has been due partly to the limited time given this phase of the problem. Our inability to establish the parasite in several important orchards indicates again the need of more extensive field operations. Observations in this state show that Macrocentrus is a distinctly desirable inhabitant of Connecticut peach orchards.

Before we were able to rear Macrocentrus successfully in any great numbers it was necessary to consider the host from a standpoint of its reaction to laboratory conditions. Some of the data obtained are included herein because of their importance in our breeding technique.

THE ORIENTAL FRUIT MOTH

Experiments with methods of inducing and preventing hibernation of the fruit moth were conducted shortly after the project was undertaken. This was done in order to make breeding work continuous during the winter. For the sake of comparison the life histories of host and parasite were considered together and showed many similarities probably accounting for the ability of Macrocentrus to survive our winters in the absence of abundant alternate hosts. The emergence of moths and parasites is merely one of these similarities (Table 1). A few other comparisons are given in Table 17.

The length of any period of the life cycle of the fruit moth may be increased by proper refrigeration, but the ill effects of this treatment may more than counterbalance the increased convenience in handling. Likewise, the length of the larval period may be altered by a change of food (Table 3), and we believe the ability to survive refrigeration is considerably affected by the quality of the food on which they are reared. The length of adult life varies when the moths are bred artificially, but may last for three weeks with proper food, temperature, and moisture. Egg deposition begins about two days after emergence from the cocoon, and may continue for four weeks (Table 17). In incubators and greenhouse during 1930 and 1931, egg deposition frequently reached a maximum four to six days after emergence, although in some cases this peak was not reached until 11 days afterwards (Figure 4). These facts are of some importance in breeding operations. For hibernating stocks it is essential to allow sufficient time to elapse for the hibernating instinct to be satisfied. Such larvae may be brought into higher temperatures after two to four months, and will usually pupate and emerge satisfactorily.

It is possible, however, to breed the fruit moth continuously throughout the season. This necessitates keeping the temperature high enough during the periods when the insect normally begins to hibernate, and continuing to breed at the same high temperatures during the winter. In 1932, our cage temperature averaged above 70° F. most of the time, and we regard the minimum for continuous work of this kind as around 75°.

TABLE 1. ORIENTAL FRUIT MOTHS AND MACROCENTRUS ADULTS FROM PARASITIZED OVERWINTERING LARVAE, 1931. SHOWING SIMILARITY IN PERIODS OF EMERGENCE

Date	Emergence of moths	Emergence of parasites
March 1		3
3	—	2
6	1	2
9	310	20
10	141	13
11	97	5
12	293	6
13	53	—
14	35	8
16	65	99
17	145	60
18	642*	28
19	363	78*
20	269	48
21	109	25
23	207	38
24	32	7
25	37	8
26	30	—
27	20	—
28	10	—
29		—

*Probable peaks of emergence.

NOTES: Placed in refrigerator in the fall of 1930 and kept there until February 17, 1931. Then put in an incubator at about 55° F. until February 25 when they were removed and placed at 75° F. until emergence.

It is also important to know the length of the different larval instars at constant temperatures in order to provide larvae of suitable age for the parasites. Some of our results are shown in Table 2. It will be seen that the first instar lasts two days in green apples at 80° F ., that the second instar begins on the third day, and that the third begins on the fourth day. Larvae five days old are nearly all in the third stage. Those reared at 80° for four days will be largely in the second, but a part in the third instar, while those reared for three days will be in the second instar. In practice, owing to the irregularity of hatching, there is some variation in the larval stages. For the most part they have been uniform if eggs are used from a single lot, obtained in a single day. After six days at 80° the larvae are too old for parasitism because more than half are in the last instar.

FOOD REQUIREMENTS

Oriental fruit moth larvae may be reared on peaches (twigs and fruit), quinces, pears and apples. Green apples are the most practical from our standpoint, and are adapted to development of the fruit moth. The life cycle in apples is slightly longer than in peaches, but the advantage of the shorter cycle when reared in peaches, is negligible, especially when losses from fruit rots of the peach may more than balance the gain in time. By storing green apples in July, 1931 and 1932, it was possible to continue breeding work during the entire winter and spring of the following years.

TABLE 2. ORIENTAL FRUIT MOTH LARVAE INCUBATED AT 80° F., 70 PER CENT RELATIVE HUMIDITY. PERCENTAGE OF EACH INSTAR PRESENT ON SUCCESSIVE DAYS

Instars	Days								
	1	2	3	4	5	6	7	8	9
First	100	100							
Second			100	76.4	2.0				
Third				23.5	97.9	75	10		
Fourth						3.8	21.6	10.9	
Fifth						21.1	68.3	89	100

NOTES: Average of two experiments, 328 larvae measured. Based on width of head capsule. Reared in green immature apples.

Thinnings obtained in July from commercial orchards were used. To supplement this supply, which began to run short during late spring, we bought an additional quantity from a grower in Georgia. We have tried unsuccessfully, or with partial success, ripe or partly ripe apples and peach twigs grown in our greenhouse. Table 3 shows that the development period is considerably shorter, and that a much greater percentage of larvae mature in green apples than in ripe apples. When reared in green apple slices, the larvae will frequently mature within the slice if this is thick enough, but we have found it desirable, especially when large numbers of larvae are used, to provide extra food in the pans on which they may complete their development.

In the spring of 1931, we were partially successful in breeding Macrocentrus and its host, using peach twigs on seedling trees and transferring them with the larvae to pans containing sound storage apples. The ratio of increase, however, was not great enough, and the method was discontinued after the first year.

ENEMIES

The chief enemies of the Oriental fruit moth reared under artificial conditions such as obtained at this Station during the course of these investigations, were fruit rots, ants, and spiders. A secondary parasite also caused considerable trouble during the summer of 1932. Something has already been said about rots and development of the larvae. It has been noticed that apples from different sources rot differently, that is, some will produce a wet, slimy mess which apparently drowns the larvae before they have time to mature, while other apples rot with less moisture and become

TABLE 3. TESTS OF DIFFERENT FOODS FOR REARING ORIENTAL FRUIT MOTH LARVAE

Food	Number eggs used	Number moths reared	Per cent maturing	Length of period, egg to adult, in days
Peach twigs	50	31	62	27.7
Ripe peaches	50	28	56	27.8
Green peaches	50	35	70	25.0
Green peaches	100	27	27	27.3
Green apples	50	50	100	30
Green apples	100	81	81	27.5
Green apples	500	229	45	31.2
Ripe apples	50	14	28	35
Ripe apples (western)	100	21	21	38.8
Ripe apples (western)	500	55	10	38.4

NOTES: All experiments using 50 eggs were carried on simultaneously in similar containers. Those using 100 and 500 eggs were carried on simultaneously, but at a different time from those using 50 eggs.

pithy or corky, allowing the larvae to escape to new food when it becomes unsuitable for development. Most of our local fruit produces a wet rot, while some of the western fruit is considerably drier. However, with none of the ripe or partially ripe fruit, has production been entirely satisfactory from the standpoint of increase.

Ants of various species have caused trouble in our breeding cages by attacking and destroying the moths. During 1931 and 1932 measures were taken against them and they were eliminated as a factor in production. Likewise spiders gave and continue to give trouble, but only require watching and destruction before they become numerous enough to cut down production.

The secondary parasite, *Dibrachys boucheanus* Ratz., caused considerable difficulty in 1932 at a critical time. This parasite attacks the Macrocentrus larva after it has spun within the cocoon of the host. It will also parasitize the Oriental fruit moth, but seems to prefer Macrocentrus larvae. In order to combat this enemy it appears to be necessary to rear all larvae in containers kept covered until emergence of the adult moths and parasites.

Larvae reared in peach twigs were subject to destruction by gum exudations, the cause of which is not fully understood. Trees in good growing condition support fruit moth larvae better than those in which growth is partly or completely checked. Losses are frequently great if proper growth is not maintained and the twigs with larvae are not removed shortly after exposure to parasites.

EFFECT OF WINTERING AND REFRIGERATION ON THE LARVAE

Hauessler states[1] that larval mortality of the fruit moth during the winter sometimes amounts to 70 per cent (in New Jersey) under field conditions. Larvae reared in the insectary in New Haven did not average this much according to our data for 1928, 1929, and 1933. Stock reared in apples and stored in the refrigerator, however, may reach this figure and it was estimated that the average mortality of all stock kept over the winter in 1932 was 65 per cent. Moisture appears to be an important factor, particularly in electric refrigerators, and all material kept here was placed in a moist box. Too much moisture so that the strips become damp is not desirable, for mold soon develops and destroys the larvae. If reared in rotting fruit, many undersized larvae spin in the strips and it is believed that these, being less hardy than the fully grown larvae, increase the mortality when attempts are made to carry them over the winter. Tests in 1932 seemed to indicate that larvae kept in an ordinary storage cellar were more successful in passing the winter than those carried through in a refrigerator. However, the most successful lot hibernated so far was one placed in an electric refrigerator in April, 1931, and removed in September of the same year. These showed a mortality of 10 per cent. Such discrepancies are difficult to explain but there are evidently many factors influencing the results that we do not fully understand. In 1933, there was much less mortality of fruit moth larvae reared in pans and hibernated in jelly glasses in an open insectary, than for those reared indoors and hibernated in the storage cellar mentioned (Table 20).

Normally, during the summer the tendency to hibernate presents no difficulty in maintaining continuous breeding. During 1930 to 1931, hibernation began to be apparent in larvae from eggs laid about the first of August. Larvae produced under these conditions practically all hibernated after the first of September in 1930, even though moved to the greenhouse where temperatures were higher than prevailed in our insectary. Likewise, with material bred during the winter of 1930 there was no tendency to continue development and very few of the larvae transformed. In 1931, we began a new schedule. All larvae were brought indoors during August and kept at a uniformly high temperature. By this means we obtained continuous emergence of moths and a good egg yield throughout the win-

[1]Jour. Agr. Research, 41: 377. 1930.

ter. For example, in March, 1932, more than 6,000 moths emerged and we secured 112,000 eggs from our cages.

As already stated, hibernation of the insectary bred larvae is progressively greater after the first of August. Undoubtedly some temperature relationship is connected with these changes in fruit moth habits, but from our experiments it is evident that short exposures of young larvae to cold do not necessarily produce hibernation (Table 4). Thus, in a series of four different treatments in which development was begun June 27 at 80° F. it is evident that four-day old larvae subjected to 45 to 50° F. for six days were not influenced. Larvae subjected to the same tıeatment, but

TABLE 4. EFFECT OF REFRIGERATION ON ORIENTAL FRUIT MOTH HIBERNATION

Refrigeration	Total larvae	Per cent hibernated
4-day old larvae hatching June 27		
None	54	11
2 days at 45–50° F.	144	11
4 days at 45–50° F.	82	1
6 days at 45–50° F.	231	6
6-day old larvae hatching July 15		
None	105	2
2 days at 45–50° F.	90	11
4 days at 45–50° F.	95	4
6 days at 45–50° F.	102	7
6-day old larvae hatching August 2		
None	14	0
2 days at 38–40° F.	34	8.8
4 days at 38–40° F.	67	5.9
6 days at 38–40° F.	55	3.6
4-day old larvae hatching August 10		
None	86	14
3 days at 38–40° F.	76	18
4 days at 38–40° F.	47	25
6 days at 38–40° F.	51	33

NOTE: All larvae were reared on green apples, kept at 80° F. before and after refrigeration. Remained at 80° for one month before examination after removal from the refrigerator.

six days old before being refrigerated, showed only a slight increase in the tendency to hibernate. For larvae refrigerated at 38 to 40° F. there was likewise a slight increase in hibernation of six-day old larvae hatching August 2. Material obtained and refrigerated in like manner August 10 showed a considerable increase in both check and refrigerated stock over those previously reared, but was greater for larvae subjected to cold in the refrigerator.

Our experience indicates that it is possible to carry larvae through the winter by placing them at 38 to 40° F. immediately after spinning. This method was largely followed in 1932.

EFFECT OF REFRIGERATION ON THE MOTHS AND EGGS OBTAINED FROM THEM

It became important at this point to know whether refrigeration of the moths, or the eggs obtained from them, would influence hibernation of the larvae in our breeding cages. A comparison of larvae from moths kept in refrigeration for three weeks with larvae from moths not subjected to refrigeration, showed no significant difference during the winter of 1932. Experiments were also conducted to learn if refrigeration has any effect upon egg-laying capacity of the females. A preliminary test indicated that three weeks' refrigeration at 38 to 40° F. considerably reduced the egg yield. A comparative test was then conducted in which moths of one, two, three and six weeks' refrigeration were placed in similar cages and kept under as nearly identical conditions as possible (Table 5). The egg

TABLE 5. EGG PRODUCTION FROM REFRIGERATED ORIENTAL FRUIT MOTHS, 1932

	Number days refrigerated				
	0	7	14	21	42
Egg-laying period, days				15*	3
Number of female moths used	50	56	58	102	50
Number eggs obtained	2,445	2,066	1,598	2,065*	41
Number eggs per female	48.8	36.8	27.5	20.2*	.8

*Average of two experiments.

NOTES: Moths confined in moist boxes in electric refrigerator at 40-45° F. Moths in egg production cages of similar size and shape kept in greenhouse under similar conditions. Period of tests January 12 to March 15, 1932.

yield was reduced for moths kept in the refrigerator for any and all periods in direct proportion to the length of cold exposure. Moths kept for seven days showed a much smaller decrease than those kept for longer periods, and in view of this it has been possible to keep moths for short periods in the course of breeding work when a surplus in this stage occurred.

During 1932 practically all egg stocks were placed at 40 to 45°, where they were kept for periods varying from a few days to two weeks. In spite of this treatment, there was no hibernation of the larvae and our moth production was not curtailed in any way. However, the egg mortality increases rapidly with prolonged exposure, as shown in Table 6, and it is consequently not advisable to keep them at this temperature more than two weeks.

EFFECT OF TEMPERATURE ON EGG-LAYING ACTIVITIES OF THE FRUIT MOTH

It was found shortly after the work was begun with the Oriental fruit moth as host for Macrocentrus, that temperature and moisture conditions had important effects upon the egg-laying phase of the moths' activities. Our first attempts at winter production were carried on in a greenhouse. Figures 2 and 3 show some of the effects of temperature variations in that

TABLE 6. EFFECT OF REFRIGERATION ON MORTALITY OF ORIENTAL FRUIT MOTH EGGS

40° F.

Number days refrigerated	Number eggs refrigerated	Date eggs were taken from refrigerator	Eggs dark spotted	Per cent eggs hatched
2	32	March 25	March 27	100
4	16	" 27	" 29	90
7	39	" 30	April 3	89
9	50	April 1	" 3	76
12	54	" 4	" 5	79
16	10	" 8	" 8	60
18	29	" 10	" 12	70
21	13	" 13	" 14	46
23	15	" 15	" 17	7
26	25	" 18	" 20	4
29	21	" 21	" 24	0
31	20	" 23	" 25	0

49° F.

Number days refrigerated	Number eggs refrigerated	Date eggs were taken from refrigerator	Eggs dark spotted	Per cent eggs hatched
2	18	March 25	March 27	100
4	20	" 27	" 29	90
7	53	" 30	April 1	92
9	35	April 1	" 3	97
12	20	" 4	" 5	95
16	50	" 8	" 8	82
18	86	" 10	" 11	81
21	17	" 13	In ref.	52
23	25	" 15	" "	60
26	31	" 18	" "	35
29	17	" 21	" "	23
31	17	" 23	" "	6
33	12	" 25	" "	0

NOTE: One larva emerged in 49° F. refrigerator on April 23. Eggs kept in jelly glasses with moist cotton in bottom. Electric refrigerator used.

house upon egg production. In view of these results, oviposition cages were moved to greenhouse incubators which were kept closed during the critical period of egg laying. The house was also kept warmer by special firing during late afternoon. Results were satisfactory. Later a special experiment was conducted in which the temperature was varied purposely and the effect noted on a number of caged fruit moths. It will be seen (Figure 4) that lowering of the temperature during the natural rise of egg laying, produced great fluctuations in the number of eggs obtained. From Figure 4 it is also evident that the peak of egg production is not reached sometimes until 11 days after emergence. Normally this occurs within a week. Our best results were obtained when the temperature was

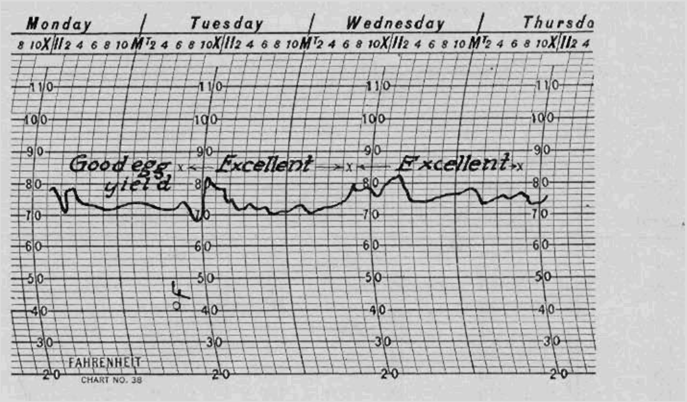

FIGURE 2. Thermograph chart showing variations in our greenhouse during favorable periods for obtaining eggs from the Oriental fruit moth.

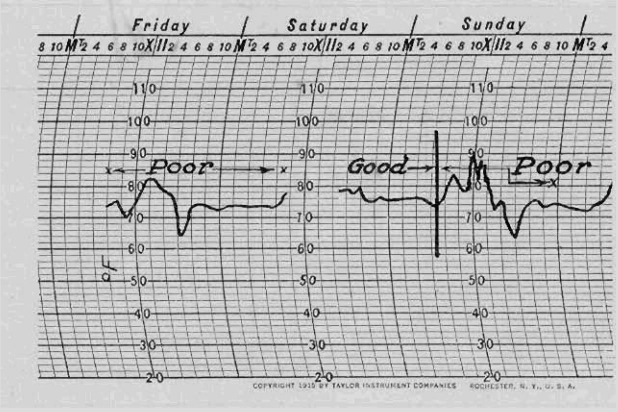

FIGURE 3. Thermograph chart showing two unfavorable and one moderately favorable period for egg-laying. The drop in temperature below 70° was responsible for almost complete failure although temperatures were high enough during the remainder of the day.

kept at 75° F. or above (not over 85°) most of the day, with special care not to allow a drop in temperature at sundown. Attempts were made at first to conduct the whole breeding work in basement incubators, but this was unsuccessful and all moths were moved to the greenhouse. With the construction of the new Jenkins Laboratory, however, breeding has been more successful in basement laboratories and compares favorably with greenhouse production during the winter. However, we continued the use of greenhouse cages and incubators (Figure 7) for obtaining eggs from the fruit moth and find it to be the most satisfactory location for this work throughout the year.

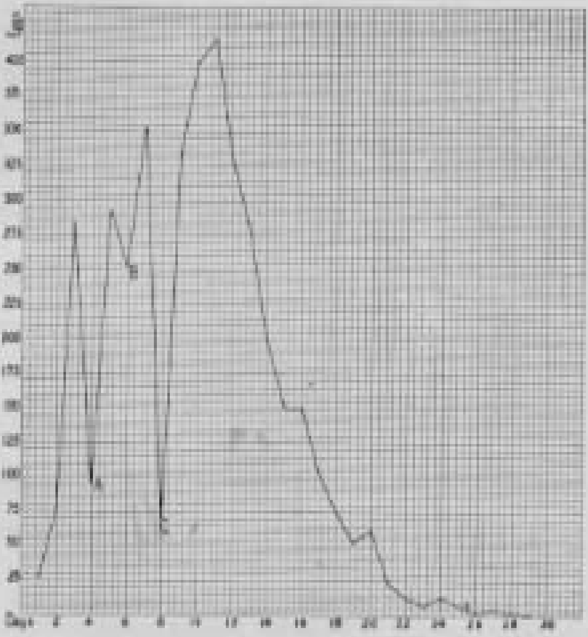

FIGURE 4. Chart showing the effects of lowering the temperature in a greenhouse where ovipositing fruit moths were kept. On days represented by A and C, the ventilators were opened enough to allow the temperature to drop below 65° F. in late afternoon. At B, the temperature dropped below 70° but not below 65°.

TIME OF EGG LAYING

When the temperature is properly regulated, egg laying takes place in general as the daylight fades. This naturally occurs in winter much earlier than in summer. Thus in November, 1932, 81 per cent of the eggs were apparently laid between 3 and 5 o'clock P. M. (Table 7), and about 89 per cent between 3 and 7 P. M. At other seasons, notably during the summer, the time of egg laying is somewhat later due to the light factor. Counts in August, 1933, showed the greatest number of eggs in our greenhouse cages were being laid between 5 and 7 P. M. Eastern standard time. On one very hot day oviposition did not take place until the temperature dropped in the evening. Little or no oviposition took place on this day construction of the new Jenkins Laboratory, however, breeding has been more successful in basement laboratories and compares favorably with greenhouse production during the winter. However, we continued the use of greenhouse cages and incubators (Figure 7) for obtaining eggs from the fruit moth and find it to be the most satisfactory location for this work throughout the year.

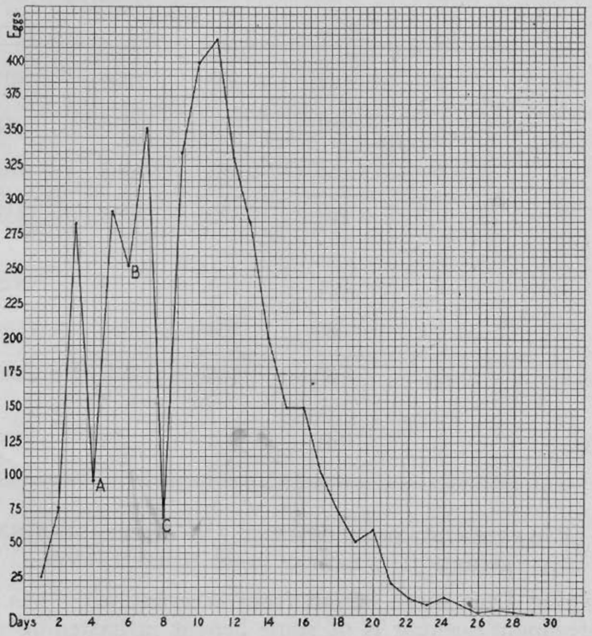

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TABLE 7. TIME OF ORIENTAL FRUIT MOTH EGG PRODUCTION

Dates	10 A.M. TO 1 P.M.	1 P.M. TO 3 P.M.	3 P.M. TO 4 P.M.	4 P.M. TO 5 P.M.	5 P.M. TO 7 P.M.	7 P.M. TO 8:30 A.M.
Nov., 1932	0	17	257	1200	301	135
	4	191	1271	955	55	146
	0	0	92	603	101	5
Totals	4	208	1620	2758	457	286
Aug., 1933	0	5	1	4	825	955
	0	80	164	555	1505	117
Totals	0	85	165	559	2330	1072
Sept. 22, 1933	0	61	503	924	4970	90

METHODS OF HASTENING DEVELOPMENT AND INCREASING EMERGENCE AFTER BRINGING LARVAE FROM HIBERNATION

After bringing fruit moth larvae from hibernation, it has become apparent that frequent soaking is of some benefit in hastening development and transformation, but the difference is not very great in the total time before emergence of the moths. From Table 8 it may be seen that fre-

TABLE 8. EFFECT OF MOISTURE ON THE LARVAE OF THE FRUIT MOTH AFTER BRINGING FROM HIBERNATION

Moisture conditions	Average period in incubator 75–85° F.	Average period in incubator: 2–2½ hours in refrigerator daily	Average period before emergence in greenhouse
Paper cells without added moisture	31 days	34 days	35.5 days
Wet every other day	30 days	31 days	34.0 days
Difference	1 day	3 days	1.5 days

quent soaking with water, with a period for drying out, hastened the average development of the Oriental fruit moth one to three days. The best treatment recorded in the series of experiments (Table 9) were those in which the larvae were wet every other day and kept in an incubator at 75 to 80° F. after they were brought from hibernation.

MASS PRODUCTION

In order to rear large numbers of larvae, it is obviously essential to have plenty of moths and to place them in convenient cages with suitable air conditions. The most successful type of cage used consists of a cloth covered frame 21 by 30 by 15 inches, placed inside a celotex incubator below a glass window.[1] The cage is placed in a shallow pan of moistened sand and peach seedlings are put inside for oviposition. The leaves of the trees should come in contact with the cloth on top of the cage for best results.

TABLE 9. TESTS OF ORIENTAL FRUIT MOTH EMERGENCE, 1929–30, AFTER SHORT EXPOSURE TO COLD AND DIFFERENT MOISTURE TREATMENTS

Date brought from hibernation	Treatment	Moisture added	Per cent pupated on January 14	Average per cent transforming Jan. 14, 1930
December 23	Greenhouse overnight; next A.M. in incubator, thereafter in incubator 75–80° F.	(1) Dry	50	60.0
		(2) Wet every other day	72	
		(3) Wet every week	64	
		(4) Wet every other week	53	
December 23	Greenhouse overnight; next A.M. in incubator, 75–80° F. Thereafter in incubator except for 2–2½ hrs. daily in refrigerator at 38–40° F.	(1) Dry	34	41.2
		(2) Wet every other day	52	
		(3) Wet every week	47	
		(4) Wet every other week	31	
December 23	Greenhouse continually	(1) Dry	51	53.2
		(2) Wet every other day	62	
		(3) Wet every week	50	
		(4) Wet every other week	50	

NOTE: Twenty paper cells with larvae in each test; brought from hibernation to greenhouse.

The incubator is regulated to 75 to 80° F. and closed in the afternoon in order to keep up the temperature.

More than 630,000 fruit moth eggs were obtained in our cages during 1931 (Table 11). The work was continued and resulted in more than a million and a half eggs in 1932. Our maximum production was reached in August, 1933, when 376,000 were obtained in one month. The greatest number obtained in one month during the winter was 80,000 in January, 1932.

Heretofore it has been considered inadvisable to breed the fruit moth during the winter because of unfavorable ratios of increase, but the last

[1]Actual dimensions of the cage are not so important as having the entire inside surfaces covered with cloth. This prevents the moths from laying eggs on the smooth wood surface of the frame.

three seasons' work has shown that this is not a serious or insurmountable obstacle. While we do not have records for the entire period in which the breeding work was carried on, we have records of some 15,000 moths confined in our cages. Their ratio of increase averaged 17 to 1 (Table 10). However, more accurate tests indicated (Table 5) that we were getting as high as 24 to 1 for moths that had not been subjected to refrigeration, and a maximum of 30 to 1 was obtained in some of the cages.

TABLE 10. ORIENTAL FRUIT MOTH RATIO OF INCREASE DURING FALL, WINTER AND SPRING; GREENHOUSE, 1931

Month	Number moths	Number eggs obtained	Potential ratio of increase
January	514	4,773	9 to 1
February	321	3,358	10 to 1
March	2,706	40,000	14 to 1
April	2,272	70,000	30 to 1
October	4,969	63,243	12 to 1
November	3,583	54,538	15 to 1
December	1,371	39,160	28 to 1
Totals	15,736	275,072	17 to 1

TABLE 11. ORIENTAL FRUIT MOTH EGG PRODUCTION

Month	Eggs	Month	Eggs
1931			
January	4,773	July	107,000
February	3,358	August	42,355
March	40,000	September	74,800
April	70,000	October	63,243
May	65,405	November	54,538
June	67,430	December	39,140
		Total	632,042
1932			
January	81,817	July	202,100
February	96,320	August	85,000
March	112,960	September	95,160
April	146,365	October	66,900
May	211,000	November	81,036
June	234,000	December	121,800
		Total	1,534,358

SEX RATIO OF REARED MOTHS

Since there has been a general predominance of male Macrocentrus in our breeding cages during the winter months, we were interested to know if this also held true for the fruit moth. It appears that the sexes of the fruit moths are more evenly divided both in collections from the field and in laboratory bred individuals, than the parasite. During July and August, 1932, the percentage of males emerging was 52. Counts made of a large number of bred overwintered stock emerging in the spring of 1932 averaged 53 per cent males, while counts made during the winter of this year showed 50 per cent males. It appears, therefore, that there is little difference between the ratio of laboratory stocks and field collected material.

OTHER HOSTS AND CLOSELY RELATED SPECIES OF MACROCENTRUS

Muesebeck[1] (1932) lists eight other hosts of *ancylivorus* besides the Oriental fruit moth. These are as follows: *Ancylis comptana* Froel., *Epiblema strenuana, Canarsia* sp., *Epagoge* sp. (Virginia 1910), *Carpocapsa pomonella* Linn. (New Mexico, 1912), and *Exartema sericorana* Walsingham (Westerly, R. I., 1917).

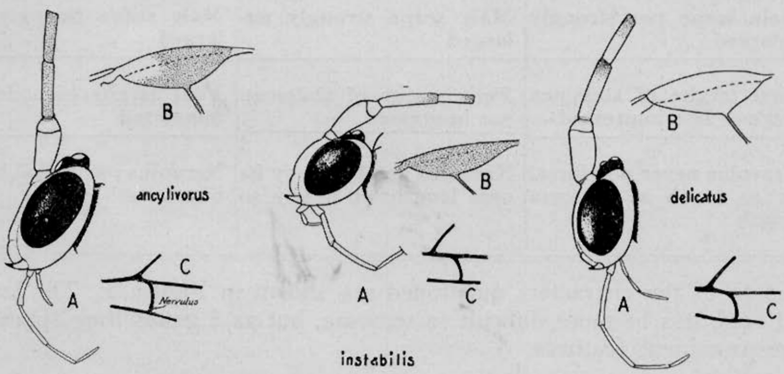

FIGURE 5. Structural differences between the three Connecticut species of Macrocentrus known to parasitize the Oriental fruit moth. A, head, showing comparative lengths of the maxillary palpi and the basal segments of the antennae; B, stigma showing absence or presence of brown color; C, structure of the nervulus of the front wing and associated veins.

These data would seem to answer the question as to whether *ancylivorus* is a native or introduced parasite, since collection records of the parasite were made prior to the date of fruit moth introduction. The record of recovery from *Exartema sericorana* is interesting because the locality is so near Connecticut. In fact, the host has been recorded al o from Connecticut and it is known that members of this genus are small leaf tiers about the size of the Oriental fruit moth. It might easily serve as an alternate host for *ancylivorus* during periods of fruit moth scarcity or inaccessibility.

Muesebeck has also analyzed the genus in detail and described several new species. The species occurring in the Oriental fruit moth are *M. an-*

[1]Muesebeck, C. F. W. Proc. U. S. Natl. Mus. 80. Art. 23, pp. 1-55. 1932.

cylivorus, M. delicatus, M. instabilis, and M. laspeyresiae[1]. Of these, we have reared *ancylivorus, delicatus,* and *instabilis* in Connecticut, although only *ancylivorus* is abundant. A tabular summary of some of the characters for separation based on the work of Muesebeck is given below.

TABLE OF CHARACTERS FOR SEPARATING THE SPECIES OF MACROCENTRUS INHABITING THE ORIENTAL FRUIT MOTH

Ancylivorus	Delicatus	Instabilis
Palpi: longest segment no longer, usually shorter than 2nd segment of antennal flagellum	Palpi: longest segment longer than 2nd segment of antennal flagellum	Palpi: longest segment longer than 2nd segment of antennal flagellum
Stigma brown with pale area at base	Stigma yellow	Stigma uniform brown
Male scape not strongly enlarged	Male scape strongly enlarged	Male scape strongly enlarged
First tergite of abdomen more or less impressed	First tergite of abdomen not impressed	First tergite of abdomen impressed
Nervulus never postfurcal by as much as its own length	Nervulus postfurcal by its own length, or nearly so	Nervulus postfurcal by its own length

Some of the characters mentioned are shown in Figure 5. The larvae will doubtless be more difficult to separate, but as a genus they appear to have prominent features.

THE LARVAL PARASITE, *MACROCENTRUS ANCYLIVORUS* ROHWER

LIFE HISTORY AND HABITS

Macrocentrus ancylivorus passes the winter within the hibernating larvae of the fruit moth or other related host. It emerges in the spring a little later than the adult fruit moth, the period of emergence lasting several weeks (May 28 to June 21, 1933). The emergence period continued for six days in our insectary in 1932 and for three weeks in 1933. Owing to the habit of delayed emergence in the fall, and to the fact that the fruit moth larvae infesting fruit are not heavily parasitized because they cannot be reached, there results a small parasite population in the spring, probably because alternate hosts are not present in abundance. The early summer percentage of parasitized fruit moth larvae is usually low in Connecticut, which may be connected in some way with scarcity of alternate hosts. During June and particularly July, fruit moth larvae are commonly available to the parasite in considerable numbers so that parasitism fre-

[1]*Laspeyresiae* is now regarded as a synonym of *instabilis* by Dr. Muesebeck.

quently increases during July. By August, 80 to 100 per cent of the twig feeding larvae may be parasitized.

It is evident in part from the length of the life cycle, which averages 28.8 days in midsummer, that three broods may develop under Connecticut conditions. There is considerable variation in time of emergence from stock parasitized at the same time so that there must be considerable overlapping of broods in the field, perhaps more so than is found in the case of its host, the fruit moth. Second and third generation adult emergence overlapped in our insectary work in 1932. Adults of the first generation emerged July 6 to July 23, those of the second generation August 1 to September 5, and the third generation from September 1 to November 15. There was no fall emergence from larvae parasitized after the first of September and in 1932 to 1933 adults emerged in June from stock parasitized the previous August, the earliest dates of parasitism being August 9 to 10 in 1931, and August 5 to 6 in 1932.

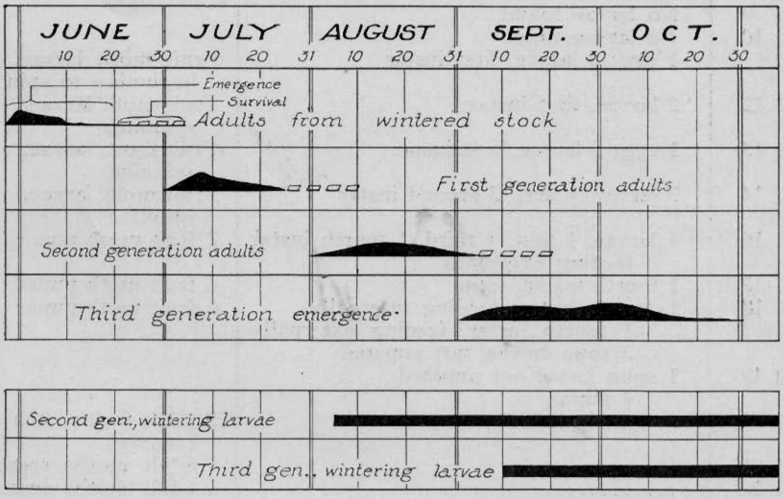

FIGURE 6. Graphic chart of Macrocentrus life history as determined by insectary breeding.

In general the life cycle from egg to adult consumes 21 to 49 days in summer, the average of 782 individuals reared during July and August 1931 being 28.8 days (Table 14). The average length of the cycle in June 1932 was 33 days, in July 29 days, in August 38 days and in September 70 days. The range according to our determinations is 19 to 88 days. There is usually a period of one to four days before egg-laying begins, which brings the total life cycle in midsummer to 30 to 33 days. The only observations on the different stages of development were made at 80° F. (Table 12). At this temperature, an incubation period of 4 to 5 days was observed and a period of 12 to 13 days from the day of exposure to the first pupation. It required 18 to 19 days to produce the first adult and the pupal period required 6 days for three individuals. The greatest emergence of parasite adults occurred two days after the greatest emergence of moths, which indicates a considerably shorter life cycle for the parasite than its host at 80°. From date of exposure to peak emergence required 20 to 21 days.

In general the life periods are very similar to those of the fruit moth. The greatest deviations are in the greater spread of the adult emergence in the case of Macrocentrus, and the longer period of emergence in the fall. Macrocentrus adults begin to emerge from overwintered parasitized

TABLE 12. COMPARISON OF LIFE HISTORY OF THE ORIENTAL FRUIT MOTH AND *Macrocentrus ancylivora* REARED AT 80° F.

Dates	Macrocentrus	Oriental fruit moth
April 6–7	Exposed on these dates	Larvae 4 days from black spot stage
April 7	No larvae found	
April 8	No larvae found	
April 9	No larvae found	
April 10	No larvae found	
April 11	1 egg; 2 larvae, first instar	Fruit moth larvae, just beginning to spin
April 12	2 larvae, first instar	Fruit moth larvae, spinning
April 13	1 egg; 5 larvae, first instar	Fruit moth larvae, spinning
April 14	7 larvae, 4 first, 3 second instar	Fruit moth larvae, spinning
April 16	4 larvae, 1 first, 1 third, 1 fourth instar feeding externally	2 fruit moth pupae
April 17	1 fourth instar, spun	4 fruit moth pupae
April 18	1 fourth instar, feeding internally 1 fourth instar, feeding externally 3 spun larvae, not pupated	6 fruit moth pupae
April 19	1 spun larva, not pupated 4 pupae	
April 20	2 spun larvae, 6 pupae	2 adult fruit moths removed
April 21	10 pupae	4 adult moths removed
April 22	....	4 adult moths removed
April 23	....	8 adult moths removed
April 25	1 ♂ 1 ♀ adult	18 adult moths removed
April 26	3 ♂ 2 ♀ adults	13 adult moths removed
April 27	7 ♂ 2 ♀ adults	5 adult moths removed
April 28	— 2 ♀ adults	1 adult moth removed
April 29	1 ♂ 1 ♀ adult	2 adult moths removed
April 30	1 ♂ 1 ♀ adult	3 adult moths removed

NOTE: These observations were made on a single lot of parasitized larvae from which samples were removed on consecutive days until April 21. The young larvae were dissected until all the parasite larvae were found to be feeding externally or were within their cocoons.

fruit moth larvae about a week after the moths begin to emerge, thus giving the host time to develop to a point where the parasite is ready to begin oviposition. The cycles of both host and parasite are so well synchronized that there would appear to be little difficulty for the parasite to survive in the fruit moth alone, especially when it is considered that larvae parasitized August 5 to 6 survived the winter successfully (Figure 6).

TABLE 13. MACROCENTRUS LENGTH OF EMERGENCE PERIODS, 1930 TO 1931

1930

Date exposed	Emerged	Length of emergence, days
July 6	August 2 — August 15	13
" 12	" 4 — " 29	25
" 15	" 5 — " 20	15
" 31	" 24 — Sept. 13	20
	Average	18

1931

Date exposed	Emerged	Length of emergence, days
March 17	April 12 — April 16	4
" 18	" 18 — " 30	12
April 21 — 2	" 13 — May 27	45
" 22 — 3	" 16 — " 28	43
" 23 — 4	" 16 — April 21	11
" 28 — 9	" 21 — May 31	40
" 11 — 12	May 9 — " 19	10
" 13 — 14	" 9 — June 2	23
" 15 — 16	" 11 — May 22	11
" 17 — 18	" 8 — " 31	23
" 20 — 21	" 15 — June 17	33
" 28 — 9	" 19 — " 17	29
May 1 (10–3 P.M.)	" 25 — " 8	14
" 12 (2 hrs.)	" 4 — " 19	15
" 16 — 17	June 8 — " 26	18
	Average of all records	21

TABLE 14. MACROCENTRUS: DATA ON LIFE CYCLE, SUMMER

Date of exposure	Number emerging	Egg to adult average, days	Egg to adult range, days
July 6	43	32	29–42
" 12	88	27.9	23–49
" 15	199	24.3	21–40
" 31	452	31.2	24–45
	782	28.8	21–49

The length of Macrocentrus adult life varies considerably. Studies on the maximum life under insectary and greenhouse conditions gave an average maximum of 15 days for both greenhouse and insectary with a range of 10 to 26 days for greenhouse and 8 to 22 days for insectary cages. The average length of life, however, probably does not exceed 10 days in midsummer. Some females live and oviposite much longer.

As indicated previously (Figure 4), the peak of fruit moth oviposition may not occur until more than a week after emergence. Similarly, the peak of Macrocentrus oviposition does not occur in midsummer until nearly a week after emergence (Tables 23 and 24). On this basis five to

TABLE 15. EMERGENCE OF ORIENTAL FRUIT MOTHS AND MACROCENTRUS FROM LARVAE EXPOSED TO MACROCENTRUS, JULY 31
Insectary Records

Species	August											September						
	17	19	21	22	24	25	27	28	29	30	31	1	3	5	7	10	12	13
Oriental fruit moths	6	1	18	29	69	50	58	2	31	30	4	7						
Macro-centrus adults					1	2	1	76	102	101	67	32	30	21	13	3	2	1

seven days would have to be added to the average length of the life cycle in midsummer, bringing the total to 34 to 36 days under favorable conditions. This would represent the time between peaks of abundance for successive generations reared from adult Macrocentrus emerging on a given date, or the time from the peak of one generation to the one following. On the other hand, as indicated, there is an unusual spread in the adult emergence of Macrocentrus from material exposed on the same day, so that different broods would soon overlap after initial spring emergence. Figure 6, based on insectary bred parasites, presents this condition graphically.

If the peak of emergence fell on June 1 as it did in 1933, then the following theoretical history would occur.

	Peak emergence		Peak oviposition		Peak emergence
1st generation	June 1	6 days	June 7	33 days	July 10
2nd generation	July 10	6 days	July 16	29 days	August 14
3rd generation	August 14	6 days	August 19	38 days	September 26

The majority of the third generation would hibernate as actually occurred, and the peak emergence of the different generations would coincide quite closely with the observed dates in our insectary. It should be pointed out that the period between emergence and peak oviposition is variable and might easily account for a shift in the length of the life periods.

However this would be relatively small and would probably not greatly influence the life cycle.

TABLE 16. MAXIMUM LENGTH OF LIFE UNDER GREENHOUSE AND INSECTARY CONDITIONS

Greenhouse

Dates of emergence	Maximum length of life
January 30	26
February 7	15
February 16	15
March 16	15
May 18	12
May 24	10
June 1	16
Average	15 days

Insectary

Dates of emergence	Maximum length of life
July 21	10
August 2	8
August 2	13
August 2	22
August 2	21
August 1	20
August 12	18
August 17	14
September 1	17
Average	15 days

COMPARISON OF THE LIFE HISTORY OF MACROCENTRUS AND ITS HOST THE ORIENTAL FRUIT MOTH

The general similarity (of the different life periods) between the fruit moth and its parasite are indicated in the following table.

TABLE 17. COMPARISON OF LIFE PERIODS OF MACROCENTRUS AND FRUIT MOTH

Periods	Oriental fruit moth, days	Macrocentrus ancylivorus, days
Egg to adult (midsummer)	31	28.8
Pre-oviposition	2—4	1—4
Oviposition	11—28	7—18
Average period adult emergence from eggs of same date	10	27
Maximum adult life	30	26

MATING AND OVIPOSITION OF THE PARASITE

As stated by many authors, mating of the parasite takes place shortly after emergence from the cocoon. Males will mate, however, for at least four days after emergence, or after prolonged refrigeration. The most suitable temperatures appear to be between 70 and 80° F., with the humidity between 40 and 80 per cent. When the temperature rises much above 80° or drops below 65° F. there is a decrease in this activity. Very strong light is not desirable.

It has been stated that oviposition occurs mainly in late afternoon and night. Although this is true in midsummer, on the approach of cool weather oviposition may occur throughout the day and is much reduced or absent during the cooler periods of morning or evening. Oviposition is furthermore continuous in our indoor cages during the day whenever temperature, light and humidity are suitably adjusted.

Temperature Relationships

Below 60° F.	Inactive	no oviposition
60 — 65° F.	Sluggish	occasional oviposition
65 — 78° F.	Active	good oviposition
78 — 90° F.	Sluggish	occasional oviposition
90° F. or above		no oviposition

We consider 70 to 75° F. and 60 to 70 per cent relative humidity to be optimum atmospheric conditions for the various activities of adult *Macrocentrus ancylivorus.*

TABLE 18. EMERGENCE OF MACROCENTRUS FROM WINTERED MATERIAL

Date exposed	Emerged fall of 1930		Emerged spring of 1931		Per cent Spring emergence
	Males	Females	Males	Females	
September 1	114	64	16	8	11.9
" 2	120	39	22	6	15.0
" 3	31	10	7	2	18.0
Totals	266	113	45	16	13.9

WINTERING HABITS

On September 1 to 2, 1930 a number of fruit moth larvae were exposed to Macrocentrus. From this exposure three males and two females emerged in October and two males in June, 1931. A much larger lot emerged as shown below in Table 18. A still larger lot was carried through the winter in 1932 to 1933. The results indicated that a small percentage of those parasitized early in August pass the winter, whereas a much larger percentage of those parasitized in September carry over (Table 19).

TABLE 19. PERCENTAGE OF MACROCENTRUS PASSING THE WINTER FROM EXPOSURES IN 1932

Dates of exposure	Per cent passing winter
August 1 — 2	0.0
" 3 — 4	0.0
" 5 — 6	0.7
" 7 — 8	0.9
" 10 — 11	3.8
" 18 — 19	9.9
" 19 — 20	14
" 23 — 24	65
" 24 — 25	40
" 25 — 26	14
" 27 — 28	56
" 28 — 29	50
" 29 — 30	21
Sept. 3 — 4	90
" 10 — 11	100
" 29 — 30	100

TABLE 20. RESULTS OF VARIOUS TREATMENTS ON WINTER SURVIVAL OF MACROCENTRUS AND ORIENTAL FRUIT MOTH, 1932 TO 1933

Dates exposed to Macrocentrus	Moths emerged	Dead larvae and pupae	Fruit moth mortality %	Parasitism %	Macrocentrus emerged, per cent of total larvae used	Estimated loss of Macrocentrus %
Ice refrigerator to May 10; May 10, insectary to emergence						
10/21 — 11/18	463	659	51	29	9	50
Common storage cellar at Mount Carmel to May 10; May 10, insectary to emergence						
11/28 — 12/9	416	292	31	35	23	37
Electric refrigerator to July 10; Indoor cage July 10 to emergence						
3/13 — 3/29	298	697	69	31	12	58
Reared in insectary where they were kept until emergence						
8/7 — 10/14	423	126	18	28	12	42

Fink states that *Macrocentrus ancylivorus* passes the winter as a first stage larvae within the host. This is easily demonstrated by examination of overwintering larvae. It is also known that eggs or spun Macrocentrus larvae do not pass the winter successfully out of doors. In view of these facts, it appears necessary to get host larvae into hibernating quarters before the parasite larvae develop beyond the first instar, and to start this hibernation at a temperature high enough to allow all Macrocentrus eggs to hatch. In 1931 to 1932 larvae were removed from breeding pans soon after spinning and placed in refrigeration at 38 to 40° F. Some of these were later removed and put in storage at Mount Carmel in a common storage cellar. Others were removed to the insectary, where they were stored in an ordinary ice box provided with ice to keep down the temperature. None of these schemes were entirely satisfactory due to high winter mortality both of parasites and hosts, but were effective in preventing transformation before the desired time. In order to decrease winter mortality, paper strips waxed with beeswax were used for the larvae, but this likewise failed to increase the percentage wintering successfully. Results of some of this work is shown in Table 19.

LENGTH OF THE OVIPOSITION OR EGG-LAYING PERIOD

It has been noted that oviposition does not begin normally until several days after emergence from the cocoon. It is of some interest to know how long the adult parasite will continue to oviposit. The following table indicates that they will continue for 18 days under suitable conditions, but in general the maximum does not average more than 12 days. It will be seen from Table 31 that 50 to 60 per cent of the adults in cages die in five days, but in the orchard unless unfavorable conditions prevail, it is probable that the average is more nearly that of the maximum obtained in insectary cages (Table 21).

Table 21. Maximum Length of Oviposition Period

Dates of exposure	Length of period, days
March 5 — 26	18
March 6 — 19	13
April 24 — May 1	7
April 23 — May 1	8
May 5 — 21	16
July 8 — 13	5
July 12 — 21	9
August 2 — 20	18
Average	12 days

The length of the oviposition period is affected in insectary and greenhouse cages by too high or too low a temperature. This also influences the longevity. Unlike some insects, whose life periods are increased in cool weather, Macrocentrus did not survive appreciably longer in the fall than in summer (August), nor was the oviposition period noticeably longer.

RATIO AND RATE OF INCREASE

Fink (7) has stated that 768 eggs have been dissected from the ovaries of a single adult Macrocentrus. This means a very high potential ratio of increase provided every egg is deposited successfully in a larva containing no others. Since this maximum is seldom reached, either under natural or other conditions, it was considered desirable to find out just what increase might be expected from material bred in our laboratories. Table 22 shows that 50 reared adults per female may sometimes be obtained. This is the average of 15 individuals. There is little doubt that certain long-lived adults produce more than this. The average of 11 tests indicate that the increase obtained in our cages was not more than 24 for each female, or, if equal sexes were considered, 12 for each individual.

TABLE 22. MACROCENTRUS RATIO OF INCREASE, 1932

Dates	Females used	Macrocentrus reared	Number per female
*March 5—26	15	757	50
*March 6—22	15	575	38
*April 22—May 1	4	63	15
*April 22—May 1	9	113	12
*May 5—23	10	165	16
*May 5—23	10	128	13
June 28—July 5	12	44	3
June 27—July 13	17	248	14
July 11—21	9	279	31
July 21—31	11	153	14
August 2—24	40	1,159	29
Totals and averages	152	3,684	24

*Tests in greenhouse.

These tests do not, of course, take into consideration losses in rearing. We know that the ratio of increase, for example, is considerably less when the fruit moth larvae are reared in seedling twigs and then transferred to apples. We also know that the ratio is considerably reduced when the fruit moth is reared in ripe instead of green apples. The figures in Table 22 are the best obtained using green apples according to our method.

Two experiments were conducted in 1932 to show the rate of increase from day to day, to learn when the greatest oviposition occurred and, if possible, how many larvae each female parasitized each day. It is evident that during the height of the oviposition period, 10 to 15 larvae may be parasitized each day by a single female (Table 23). Under the conditions of experiment the maximum oviposition occurred between the eighth and tenth day after emergence in one case, and between the seventh and tenth day in the other. After the tenth day, oviposition dropped off rapidly in both instances. The greatest mortality was evident after the first day, which was probably due to previous treatment of the adults. Two other tests (Table 24) indicated, however, that oviposition may continue at a maximum for 14 days under favorable conditions.

The ratio of increase was not influenced (Table 25) by refrigeration up to 13 days at 40 to 45° F. This treatment likewise had no effect upon the sex ratio. It is believed that longer periods of refrigeration at this temperature are not desirable since they tend to weaken the adult and shorten its life.

TABLE 23. RATE OF INCREASE ON SUCCESSIVE DAYS

Experiment 1

Dates	Number females present each day	Macrocentrus reared	Number per female	Per cent males
March 6	15			
" 7	9	65	4	69
" 8	9	58	7	63
" 9	9	57	7	59
" 10	7	84	9	79
" 11	7	40	5	85
" 12	7	50	7	62
" 13	—	40	5	60
" 14	5	45	9	85
" 15	5	51	10	82
" 16	4	60	12	93
" 17	3	3	.7	66
" 18	2	5	1	40
" 19	2	8	4	87
" 20	2	0	0	0
		575		74

Experiment 2

Dates	Number females present each day	Macrocentrus reared	Number per female	Per cent males
March 5	15			
" 6	8	93	6	46
" 7	—	90	11	63
" 8	—	78	—	65
" 9	6	73	—	45
" 10	5	82	13	53
" 11	5	60	12	53
" 12	4	76	15	42
" 13	4	36	9	61
" 14	4	53	15	45
" 15	4	51	15	78
" 16	4	37	9	78
" 17	4	5	1	80
" 18	3	3	.7	66
" 19	3	4	1	100
" 20	3	0	0	0
" 21	3	6	2	83
" 22	3	0	0	0
" 23	3	10	3	10
" 24	3	0	0	0
" 25	3	0	0	0
		757		56

TABLE 24. DAILY PARASITISM, LONGEVITY AND RATIO OF INCREASE EXPERIMENT, 1932

Date	Cage 1: Number Macrocentrus placed in cage — Males	Cage 1: Number Macrocentrus placed in cage — Females	Cage 1: Number Macrocentrus reared	Cage 2: Number mated females in cage	Cage 2: Number Macrocentrus reared
Nov. 1	10	10	1	10	4
" 2			11		23
" 3			46		21
" 4			37		39
" 5			47		43
" 6			35		31
" 7			18		16
" 8		8	10	3	28
" 9		8	26	3	17
" 10		8	21	3	23
" 11		7	28	2	9
" 12		7	34	2	7
" 13		5	13	1	2
" 14	3	4	16	1	0
" 15	2	3	30		
" 16	2	3	29		263
" 17	2	3	12		
" 18	1	2	5		
" 19	1	2	9		
" 20	0	2	4		
" 21		1	1		
			435		

NOTE: 63 per cent males; increase 43 per female; 16 females per female reared; longevity 21 days.

NOTE: 38 per cent males; increase 26 per female; 16 females per female reared; longevity 14 days.

TABLE 25. COMPARISON OF SEX RATIO, AND RATIO OF INCREASE, USING REFRIGERATED AND NON-REFRIGERATED MACROCENTRUS

Refrigeration[1]	Number Macrocentrus used	Number reared: Males	Number reared: Females	Ratio increase per individual	Increase per female	Females per female	Per cent males
None	30 ♂ 30 ♀	634	201	14	27	6	75
3 days	30 ♂ 30 ♀	464	216	11	22	7	68
None	30 ♂ 30 ♀	233	145	6	12	4.8	61
7 days	30 ♂ 30 ♀	294	221	8	16	7	57
None	30 ♂ 30 ♀	261	322	9.7	19	10	44
13 days	30 ♂ 30 ♀	304	152	7	14	5	66
Totals for none	90 ♂ 90 ♀	1128	668	9.9	19.9	7.4	62
Totals for refrig.	90 ♂ 90 ♀	1062	589	9	18.3	6.5	64

[1]40–50° F.

EFFECT OF HIBERNATION ON SEX RATIO AND RATIO OF INCREASE

In order to learn if hibernation has any effect on the ratio of increase or upon the sex ratio, four cages of equal size were provided with adults, approximately the same number of females being used in each cage. These data are shown in Table 26, and indicate that the ratio of increase is not less in the case of hibernated stock. Accordingly, there should be no disadvantage in liberating hibernated Macrocentrus in orchard work.

TABLE 26. EFFECT OF HIBERNATION ON INCREASE AND SEX RATIO OF MACROCENTRUS

Treatment	Number females used	Number reared per female	Per cent males
Freshly reared	21	25	56 and 66
Hibernated	19	33	49 and 69

These tests were all made simultaneously during August. Cages of equal size were used and large quantities of fruit moth larvae were provided throughout in each cage. The hibernated stock was held over in a refrigerator until July.

SEX RATIO

It was observed during 1930 that approximately five females to every four males emerged from stock collected in the field in New Jersey during June and July. Since this ratio was based on a count of 9,000 individuals, it was considered significant. The count was, however, repeated again in 1931 and the ratio found to be the same within 1 per cent. Macrocentrus bred under artificial conditions in 1930 began with approximately the same number of males in midsummer, but the ratio of males increased as the summer advanced until three males to every female were often obtained. During the course of these experiments, several factors have been investigated. Temperature seemed to play an important part, but a predominance of males often remained even when reared under controlled temperatures. It is true that mating occurs most readily between 70 and 80° F., so that the decrease of females noted in 1930 may have been due to temperatures below the optimum for this activity, in that an excess of unfertilized females resulted. However, in 1932, cages similar to some of our greenhouse cages kept in the insectary during August gave 57 per cent males for 1,159 individuals, whereas 15,000 Macrocentrus reared in our greenhouse between January and June gave exactly the same percentage.

It was thought possible that the age of the exposed fruit moth larvae might affect oviposition by unmated females. There is an indication that the age has some effect (Table 27), but results are variable and it is apparent that other factors are more important. Experiments were then made with special mating cages in which equal numbers of males and females were first placed, then excess males, and finally only known mated females. Results of these tests are shown in Table 28. It would appear from the figures that methods of handling the adults before placing them in the cage for exposure to fruit moth larvae, constitutes a very important means of reducing the unfavorable sex ratio of this species in the laboratory.

In view of the foregoing facts, attempts were made to breed Macrocentrus by means of a special mating cage that contained a large number of males, transferring the females after one day to a second cage with fruit moth larvae. This method was also directly compared (Table 24) with the method by which the sexes were equal in number and exposures to fruit moth larvae were made in the cages without transference of the females. It became evident that the extra operation was laborious, the loss of females even in the special mating cage for one day was considerable, and the final results in production were discouraging. Incidentally (Table 24) it became evident that the actual increase of females for each female was no greater in the case of the mated and transferred individuals as compared with parasites placed in the cage without previous mating. Finally a series of seven cages was used in the following way in order to increase the percentage of females reared.

TABLE 27. TESTS WITH DIFFERENT AGE OF FRUIT MOTH LARVAE FOR EXPOSURE TO MACROCENTRUS

Age of fruit moth larvae[1], days	Per cent male Macrocentrus	Number tests	Number Macrocentrus reared
7 to 9	82	5	92
6 to 7	64	13	396
5 to 6	59	8	193
4 to 5	60	10	243

[1]From black spot stage, held at 80° F.; reared in green apples.

All adults from emergence cages (stock emerging in one day) were placed together in cage 1. After one day the males were collected and placed in cage 2, together with the males and females emerging the second day. This gives an excess of males in cage 2, but in order to prevent losses of females from too large an excess, such as occurred in previous tests, only enough males are used to bring the ratio to 2 to 3 males for every female. On the third day this is continued with cage 3, and so on until the end of the week, when the process is repeated with cage 1. Results with this procedure so far have been satisfactory and indicate that 50 to 55 per cent females are easily secured with the method.

RATIO OF FRUIT MOTH EGGS TO NUMBER OF MACROCENTRUS REARED

In order to give some idea of the number of fruit moth eggs needed for rearing a stated number of parasites, it is interesting to note that during a successful breeding period (August, 1931) we used a total of 42,000 fruit moth eggs. With this number a total of approximately 3,000 Macrocentrus was reared, or in other words, 14 fruit moth eggs were required for each adult parasite. Occasional lots of these eggs were used to keep up stocks of fruit moths, but there was apparently not too great a surplus of host material on which to draw. During other periods much larger quantities of host material have been used, but with greater skill and refinement of methods the ratio should be less, if anything, than that quoted. We have already shown that it is possible to obtain considerable numbers of fruit moth eggs during the winter.

TABLE 28. EFFECT OF DIFFERENT TREATMENTS ON THE PERCENTAGE OF MALES

Treatment	Dates	Number reared	Per cent males
Equal number males and females in mating cage; 1 day in mating cage; only females in exposure cage.	Feb. 9 - 16	338	70
Equal number males and females in mating cage; 2 days in mating cage; only females in exposure cage.	Feb. 9 - 16	457	70
Large excess males in mating cage; 1 day in mating cage; females only in exposure cage.	Mar. 5 - 26	757	56
Equal number males and females in mating cage; 1 day in mating cage; only females in exposure cage.	Mar. 6 - 22	575	81
10 known mated females in exposure cage without males.	May 5 - 21	128	46
10 females from screen of emergence cage with large excess males; only females in exposure cage.	May 5 - 21	165	52
10 females, 10 males in exposure cage.	Nov. 1 - 21	435	63
10 known mated females in exposure cage without males.	Nov. 1 - 13	263	38

As seen in Table 11, more than 800,000 eggs were obtained during the first six months of 1932. At a ratio of 14 to 1 it would be possible to rear 57,000 adult Macrocentrus in six months. From the practical standpoint, however, it appears difficult to produce them even at a ratio of 14 to 1 because of mortality in hibernation which we have so far been unable to prevent. Our total emergence for the first six months of the year was 26,299, or about half the number estimated. Nevertheless it is possible to rear the parasite in considerable numbers. Some of our production records are shown in Table 29. In 1932, we determined to rely mainly on our own laboratory bred Macrocentrus for distribution. We obtained for this purpose about 7,500. This required the entire time of one man throughout the season, but the possibility of greater production than has been realized hitherto, together with the advantage of obtaining the parasites at more favorable periods, made it seem desirable to continue the arrangement.

TABLE 29. MACROCENTRUS PRODUCTION BY ARTIFICIAL MEANS, 1930–1933

Month	Macrocentrus reared			
	1930	1931	1932	1933
January		187	1618	2480
February		33	2203	1591
March		456	3682	2362
April		678	3581	1284
May		596	4476	2160
June		1074	7639	8154
July	2038	351	2887	3210
August	2051	2398	3735	7444
September	1948	841	2809	6106
October	1599	836	2139	17829
November	303	859	2135	5035
December	237	744	2606	1247
	8,176	9,053	36,854	58,900
Total for four years	112,983			

During 1933 we made use of a basement room where attempts were made to regulate temperature and humidity within 70° to 78° F. and 60 to 70 per cent humidity. Production proceeded satisfactorily and reached 500 daily for a short period in June. Fruit rots then began to develop and it was necessary to place all slices in a drying cabinet kept around 50 per cent saturation with calcium chloride. Production again reached 300 daily in August but the most important time for liberation in the orchard was not covered.

Four thousand five hundred Macrocentrus were liberated in 1933. Our total production, however, was greater in 1933 than in any previous year. It totalled more than 58,000 reared adults, and about 15,000 estimated in storage December 1.

PERCENTAGE PARASITISM IN LABORATORY BREEDING

During 1930 we experimented with peach twigs and green apples to obtain data on the percentage of parasitism in our cages. Naturally the percentage was higher in twigs than in fruit because of the greater accessibility in twigs. Notwithstanding, it appears possible to obtain parasitism of the Oriental fruit moth as high as 76 per cent in apple slices. For quantity breeding, however, 50 per cent is high enough, inasmuch as this allows considerable leeway for keeping up stocks of the host. During the fall of 1931 parasitism of larvae in apple slices averaged about 30 per cent, but during the winter of 1932 parasitism amounting to 40 to 50 per cent was frequently obtained. Table 30 shows some of the results obtained in parasitizing larvae in twigs and in apple slices.

TABLE 30. PERCENTAGE OF PARASITISM POSSIBLE WHEN TWIGS AND APPLE SLICES ARE USED FOR EXPOSURE TO MACROCENTRUS ADULTS, 1930

Oriental fruit moth larvae in	Dates of exposure	Moths emerging	Macrocentrus emerging	Per cent parasitism
Twigs	July 9–10	43	102	70
	July 12	12	87	87
	July 14	13	14	51
	July 16–18	20	80	80
	June 26—July 4	11	54	83
Totals		99	337	77.2
Apple slices	July 15	62	199	76
	July 15–17	206	217	51
	July 16–18	51	59	53
	July 18–19	55	72	56
	July 25	142	157	52
	July 24–25	22	20	47
	Aug. 1	65	32	33
	Aug. 6	185	54	22
Totals		788	810	51.3

ENEMIES

Ants, spiders, and secondary parasites cause considerable trouble in Macrocentrus production. We have had cages of parasites completely destroyed by ants; spiders show an equal fondness for the parasites if they get into a cage. Ant baits and repellents freely used on the greenhouse benches, have prevented damage. Spiders may be kept in check by brushing them from the eaves and corners of the greenhouse and cages at frequent intervals. The secondary parasite, *Dibrachys boucheanus* Ratz., caused some trouble in 1932, reducing our summer production by about 2,000 reared adults. These enemies have a shorter life cycle than the parasite and work on both the fruit moth and Macrocentrus. Covered breeding pans and destruction of infested stock has largely but not entirely eliminated this pest from emergence cages.

EFFECT OF INSECTICIDE DUSTS ON MACROCENTRUS LONGEVITY

In a previous bulletin of this Station it was suggested that farm practices would probably be of considerable benefit in helping Macrocentrus maintain itself. For example, some means of carrying the insect over the winter is necessary and is doubtless provided in natural conditions surrounding many orchards. Natural cover and alternate hosts could, if necessary, be provided.

Another factor influencing parasite abundance lies in the effect of common spray practices on the length of life or egg laying ability. It would perhaps not be suspected that an insect of the size and activity of Macrocentrus could be affected by sulfur. However, laboratory experiments indicate that such is the case, though what effect it may have in the field has not yet been demonstrated. Our plan of experiment consisted of using cages of equal size in which were placed adults of the same age. Undusted peach seedling trees were put in half the

TABLE 31. EFFECT OF SEVERAL ORCHARD DUSTS ON THE LONGEVITY OF MACROCENTRUS ADULTS

Treatment	Number Macrocentrus used	Number tests	Per cent survival after 5 days
Sulfur dust	180	6	10
Check	180	6	59
Lime dust	120	4	52
Check	120	4	49
Talc dust	120	4	45
Check	120	4	57
Lime—lead arsenate—oil dust	300	10	28
Check	270	9	52

cages. In the other half were placed trees of the same size dusted lightly with sulfur or other material. Since temperature plays an important part in such an experiment, care was taken to keep the temperature in all cages the same and not to allow it to go too high. After five days the live individuals in all cages were counted. It will be seen (Table 31) that the most injurious material was sulfur dust, one of the most commonly used fungicides in any commercial peach orchard. In experiments with this material only 10 per cent of the adults survived after five days, whereas 59 per cent of those in control cages were alive. Lime and talc had little or no effect in these tests, but lime—lead arsenate—oil dust increased the mortality considerably.

IMPORTANT CONSIDERATIONS IN BREEDING WORK

In our breeding program it appears that important consideration should be given to the following points.

ORIENTAL FRUIT MOTH

1. *Prevention of hibernation.* In order to prevent fruit moth larvae from hibernating in the fall when the tendency is strong, it is necessary to bring all stocks indoors in August and breed at 75° or above.

2. *Egg deposition.* Our best results in securing eggs of the Oriental fruit moth have been from the use of greenhouse incubators with glass tops. These should be regulated to 75 to 80° F. Seedling peach trees are used within the cages and the eggs are laid on the leaves.

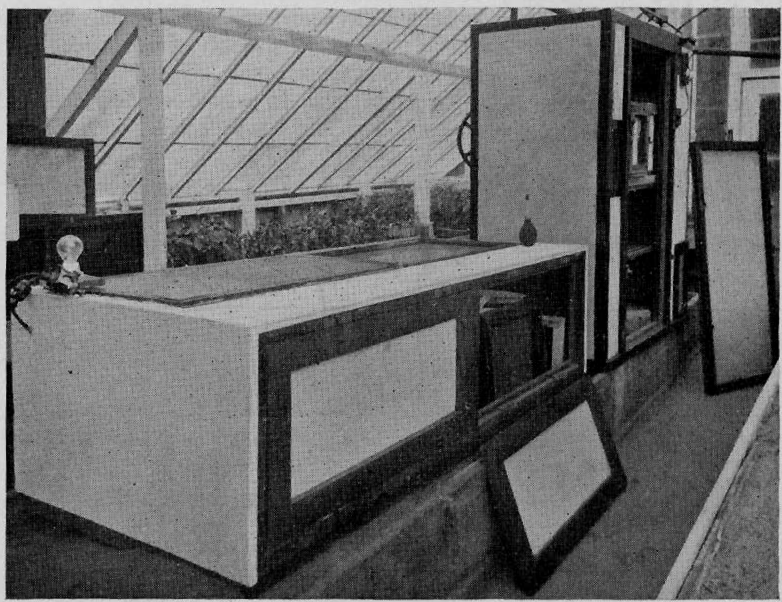

FIGURE 7. Two types of greenhouse incubators used for confining Oriental fruit moths. Both are provided with light bulbs for head, thermoregulators, and a small fan.

3. *Food for the larvae.* Food for the larvae appears to be as important, if not more important, than the two preceding factors. Many more larvae develop in green than in ripe fruit and the life cycle is shorter.

4. *Successful hibernation of the larvae.* This problem is not fully solved, but it is fairly simple to make the larvae enter hibernation by removing them from breeding pans soon after they have spun their cocoons and then placing in refrigeration at 38 to 40° F. Another successful plan as carried out in our laboratory consists of placing the apples containing half grown larvae in a 60° room where the larvae are allowed to spin their

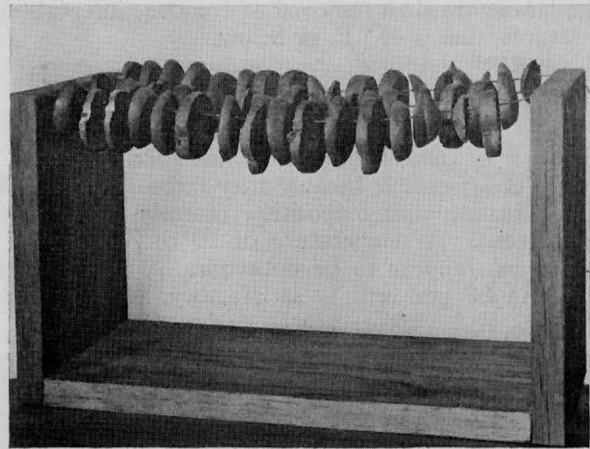

FIGURE 8. Apple slices infested with Oriental fruit moth larvae ready for exposure to parasites.

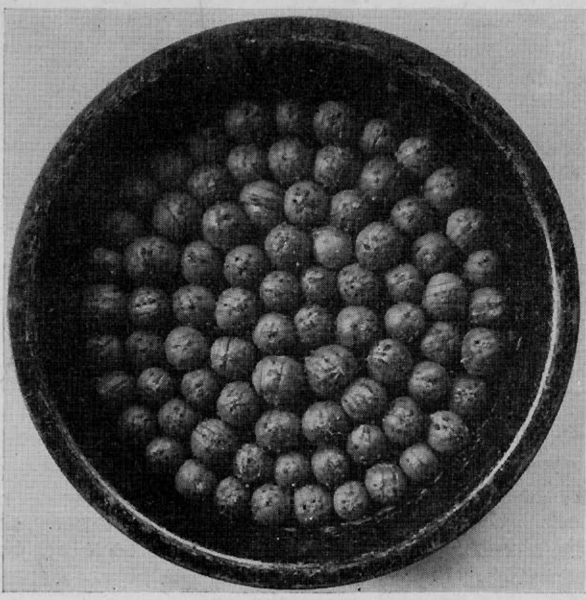

FIGURE 9. Pan of green apples sliced and infested with larvae before separating as shown in Figure 8.

cocoons. The larvae are then removed at frequent intervals to full hibernating temperatures, that is 45° F. or below.

MACROCENTRUS ANCYLIVORUS

1. *Maintenance of temperature and moisture.* Proper heat, light, and moisture are indispensable because they increase the life and promote the activities of mating and oviposition essential to maintenance of a high rate of increase. A temperature of 70 to 75° F. and a humidity of 60 to 70 per cent appear to be optimum. A range between 70 and 78° F., and 40 to 80 per cent is satisfactory. Strong light and high

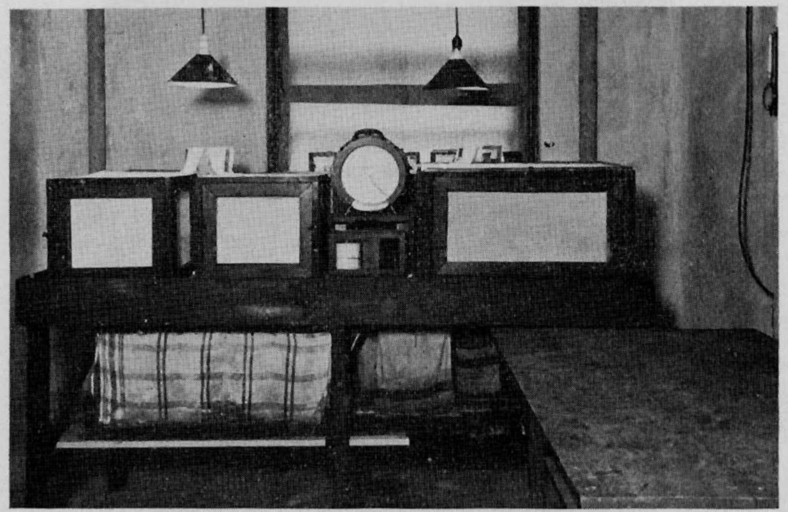

FIGURE 10. Macrocentrus breeding room showing method of lighting cages and the type of cages used. The cages are set in a bed of sand.

humidity should be avoided. Oviposition is continuous in weak daylight or with a 25 W blue daylight bulb placed about one foot from the top of the cage (Figure 10).

2. *Food.* Second and third instar fruit moth larvae may be used. Larvae kept at 80° four days after hatching, will be found to be largely in these stages. After five days all, or nearly all, will be in the third instar. We regard the third instar as the most desirable. Lump sugar or honey may be used to feed the adults.

3. *Successful hibernation.* Parasites hibernate largely as first stage larvae. If too old they will die, and if the eggs have not hatched when placed in hibernation, they will be killed by the host. Parasitized larvae should therefore be removed from the pans or containers as soon as they have spun, and placed in a cool place for hibernation. Use of the 60° room as mentioned for fruit moth larvae is helpful.

BREEDING SCHEDULE[1] FOR REARING MACROCENTRUS EMPLOYED AT THE CONNECTICUT EXPERIMENT STATION FROM 1931 TO 1933

1. Place green apple thinnings 1 to 1½ inches in diameter in cold storage, (July).
2. Obtain Oriental fruit moth eggs from greenhouse incubators (Figure 7). Eggs may be held in refrigerator not more than two weeks.
3. Place eggs on apples cut in slices (Figure 9) one-fourth inch thick. So that the slices will stay in place, the apples are not cut all the way through. Put 2,000 to 5,000 eggs (up to 8,000 have been used) on a pan of 50 to 60 apples. Slices are separated slightly, which allows the larvae to enter easily.
4. Remove apples after four to five days at 80° F., separate slices, and mount on rack as shown in Figure 8. The larvae are now ready to expose to parasites.
5. Place slices with larvae in parasite cage held at 70 to 78° F. and 60 to 70 per cent relative humidity. Elevate racks until slices are

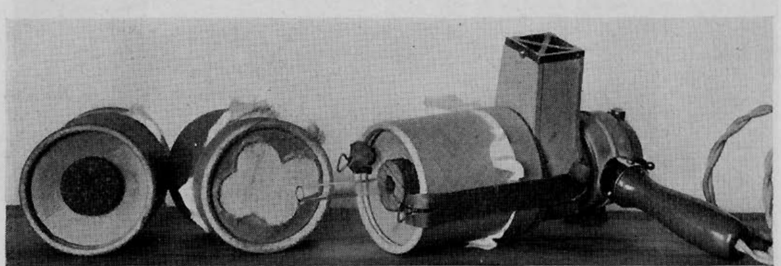

FIGURE 11. Paper boxes attached to a small hair dryer for collecting moths and parasites. The hole in the end in which the glass spout is inserted is plugged with a cork (as shown in the left hand figure), when the desired number of insects are obtained. These boxes are also used for shipping Macrocentrus adults to points within Connecticut.

about one inch from the top of the cage. For type of cages used see Figure 10.

6. Remove slices after 24 hours and place in breeding pan at 75 to 80° F. Keep humidity as low as possible (50 per cent) to prevent wet fruit rots. After several days add punctured green fruit which the larvae leaving slices can enter to complete development. Keep larvae for hibernation at 60° after they have left the slices. Those required for breeding stock need not be kept at 60°.
7. Remove larvae spun in corrugated strips as fast as they spin their cocoons, and place them in hibernation.
8. For breeding stock make use of emergence room (Figure 12). Collect adults from the light screen with suction device (Figure 11).

[1]Our method is considerably different from that employed by Daniel and others, (3) pp. 16-27. 1933.

MACROCENTRUS PARASITES OBTAINED IN NEW JERSEY IN 1930 AND 1931

Owing to the failure to secure Macrocentrus by artificial breeding in sufficient quantities for liberation in 1930, arrangements were made to send men into New Jersey to collect parasitized larvae in the field. Work was begun June 1, and both strawberry leaf roller and Oriental fruit moth larvae were obtained. Material collected in the vicinity of Moorestown during the early part of June yielded few Macrocentrus. This period was apparently not early enough and was between broods both for the peach moth and its larval parasite, Macrocentrus. Collections made later in June and early in July yielded nearly 60 per cent Macrocentrus. The yield of Macrocentrus from strawberry leaf rollers

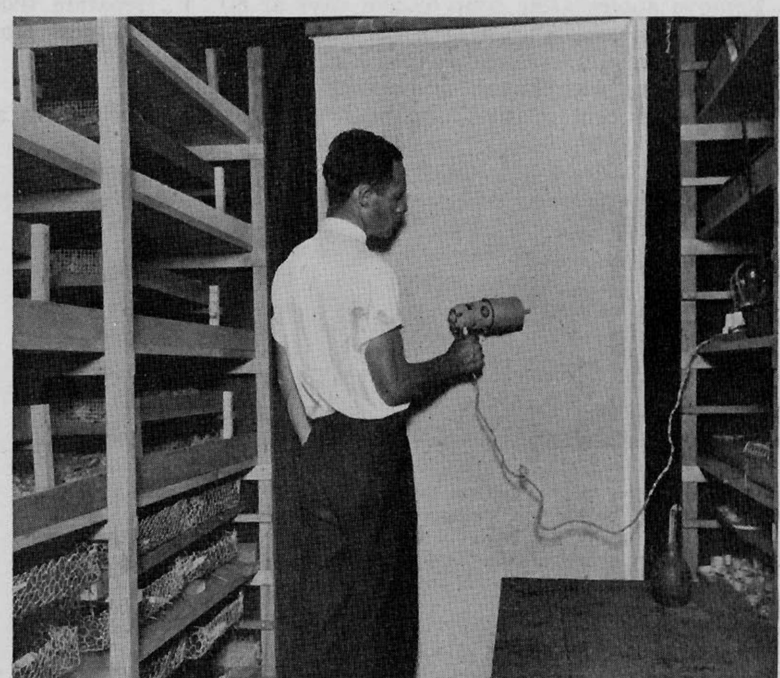

FIGURE 12. Interior view of emergence room used for both Macrocentrus and Oriental fruit moth. The walls of the cage are of black cloth with only a light window which concentrates the insects on that side.

was poor, there being apparently a much higher parasitism by *Cremastus cookei* than by *Macrocentrus ancylivorus*. Strawberry leaf rollers obtained in the fall of 1929 were used to furnish breeding material during the winter and spring of 1929-30.

On arrival in New Haven, the fruit moth larvae in peach twigs were placed in shallow pans with moist cloths in the bottom, and the twigs supported by one-inch chicken wire. On the wire between twigs were placed punctured green apples, to which many of the larvae transferred on leaving the twigs. These trays with twigs and green apples were then placed in a 7 by 7 by 7 foot cage with a light screen for collection of the parasites (Figure 15).

In 1930, we secured from field collections of 20,000 folded strawberry leaves and 35,000 infested peach shoots, a total of 9,590 Macrocentrus adults. In addition we obtained from the U. S. Bureau of Entomology nearly 3,000 more. In 1931, arrangements were made with the Federal Bureau at Moorestown, N. J., to obtain a supply of strawberry leaf rollers and parasitized fruit moth larvae, which were shipped to us at New Haven. As in 1930 the material was placed in our emergence cage and the parasites collected from the light screen with a hair dryer suction device (Figure 14). They were transferred by this means from the screen to paper boxes, which were packed in moist sphagnum, and sent to growers. This year some parasites were lost through overcrowding and rapid molding of strawberry leaves, due to lack of space in the cage. A comparison of the numbers obtained in 1930 and 1931 is given in Table 32.

TABLE 32. DATA ON MACROCENTRUS OBTAINED FROM FIELD COLLECTIONS IN NEW JERSEY

Year	Peach twigs	Strawberry leaves	Number Macrocentrus	Per cent males
1930	35,000	20,000	9,590	41
1931	50,000	110,000	11,630	42

TABLE 33. STATISTICS OF MACROCENTRUS DISTRIBUTION 1930 TO 1933

Year	Total number distributed	Number growers supplied	Number colonies less than 100	Number colonies more than 100
1930	11,600	142	120	30
1931	10,736	167	141	39
1932	9,500	47	0	47
1933	4,784	22	1	21
Totals	36,620	239[1]	162	137

[1]Does not include duplicates from year to year.

FIELD LIBERATIONS OF MACROCENTRUS AND OBSERVATIONS ON THEIR EFFECTIVENESS

In 1929 we began liberations of *Macrocentrus ancylivorus* in Connecticut orchards. The first liberations were made in the Rogers orchard at Southington and the Root orchard at Farmington. Owing to the rise of natural parasitism at the Rogers orchard, the results were obscured. At the Root orchard 300 Macrocentrus obtained from New Jersey were released in August, 1929. This was followed in July and August, 1930, with 125, and with 160 in 1930. The history of Macrocentrus parasitism in this orchard took the following course. In 1929 no Macrocentrus could be found in any collection. In 1930 some were found early in the season, but none later. In 1931 the parasitism was low early in the season, but increased rapidly, reaching almost complete parasitism in August. In 1933 without further introduction of this species, almost total parasitism of the second brood occurred in July.

In the Pero orchard at Manchester, 500 Macrocentrus were liberated in June, and 50 in July, 1930. Two hundred more were liberated in July and August, 1931. Larval parasitism by Macrocentrus reached a high point August, 1931, probably because of the large liberation in 1930. No Macrocentrus could be found in this orchard in 1930. In several other orchards where small liberations were made in 1930 none could be found in 1931. Our experience indicates, however, that rapid multiplication of the parasite does not always take place.

Thus in the College orchard at Storrs (Connecticut State College) no Macrocentrus were recovered at all in 1931 and 1932 and it was not until 1933, one year after liberations, that the first recovery was made. Furthermore there was not sufficient larval parasitism in 1933 to check fruit moth infestation, which appeared to be fully as severe in late peaches (Hales) as during the previous year.

In addition to the above mentioned orchards, observations have been made in several places where the fruit moth infestation was just beginning at the time of parasite liberation. In at least one other case besides the Root orchard parasitism was apparently able to keep the infestation from reaching a high figure such as occurred in the Rogers and surrounding orchards in 1929. In a few cases we have been unable to establish Macrocentrus successfully but we may be successful with continued efforts. In these orchards damage by the Oriental fruit moth continues to be serious.

From orchard inspections it seems as though Macrocentrus is now well distributed in the central portions of the state. There are still some orchards within this area where the species cannot be found and it remains to be seen whether it will be necessary or advantageous to reintroduce the species in cases of recurring infestations. It is hoped that where successfully introduced the parasite will become so thoroughly established on the fruit moth and other alternate hosts that it will return in sufficient numbers to check a rising infestation whenever it occurs. Macrocentrus liberations will then be no longer necessary or desirable.

It is quite evident from field collections that *Macrocentrus ancylivorus* will live from year to year in the same orchard in Connecticut.

The best time for liberations seems to be during those periods in which twig injury is just beginning. It is apparent from laboratory experiments that fruit moth larvae are most readily attacked in the first to third stage, or instar. Where abundant twig infestation occurs, it is desirable naturally to release them as early in the summer as possible. This occurs in favorable seasons in Connecticut about the middle of June. It is not always possible, however, to secure the desired number of parasites at the precise time when they should be released. In such cases it appears to be better to release late than not at all. The two most favorable periods in Connecticut appear to be from June 15 to 30, and from July 15 to about August 5.

Naturally the more Macrocentrus that can be released in an infested orchard, the better the chance of establishing the colony succesfully. Our results with small liberations were not encouraging during the first two years of the work and we consequently discontinued liberations of less than 100 individuals at one time.

As to the effectiveness of parasitism by this species in Connecticut it is apparent from Table 33 that considerable benefit to the orchardist occurs whenever parasitism of the second brood larvae is high. There are, of course, other factors influencing abundance of the Oriental fruit moth that may cause the infestation to vary from year to year. Some of the more prominent of these appear to be (1) the growing condition of the orchard which depends on cultivation, pruning, fertilization, and other factors; (2) the evening temperatures during the flight of the third brood moths from the middle of August to the middle of September; (3) parasitism by other species such as Trichogramma, Glypta and others. All of these points make it difficult and laborious to predict within reasonable limits what an infestation will be. However, by determination of second brood larval and egg parasitism we have been able to state whether an infestation would be large or small at picking time.

TABLE 34. COMPARISON OF PARASITISM BY MACROCENTRUS AND DEGREE OF ELBERTA INFESTATION THE SAME SEASON

Orchard and location	Year	Parasitism of second brood larvae	Per cent infested Elbertas	Notes
Connecticut Agricultural Experiment Station Mount Carmel	1933	93	7	Average of drops and picked
Bishop Farms Cheshire	1932	89	10	Average of drops and picked
Pero Brothers Manchester	1931	high	8	Count of drops: picked fruit less
	1932	75	8	Count of drops: picked fruit less
	1933	85	11	Count of drops: picked fruit less
L. C. Root & Son Farmington	1933	85	16	Count of drops: picked fruit less
Connecticut State College Storrs	1931	0	80	Average of picked and drops
	1932	0	50	Average of picked and drops
	1933	2[1]	72	Average of picked and drops

[1]Total larval parasitism (Glypta and others) 17 per cent. Macrocentrus introduced in August, 1932. First recovery August, 1933.

It appears finally that the general uncertainty of parasite control of the Oriental fruit moth is dependent in some way upon the inability of the parasites to develop in certain localities and serves only to emphasize the statement made at the beginning of this series of papers, namely, that there is great need for continued study in this line, both in field and laboratory.

ACKNOWLEDGMENTS

During the course of the work with fruit moth parasites much help has been received from others. Construction of apparatus has been in the hands of J. F. Townsend. Photographs were made by B. H. Walden. Encouragement and advice have been freely given by Director W. L. Slate and Dr. W. E. Britton. And finally, much credit is due to the Connecticut Pomological Society which has contributed financially and supported the project firmly from the beginning.

SUMMARY AND CONCLUSIONS

THE ORIENTAL FRUIT MOTH

1. The Oriental fruit moth is reared more easily on green immature apples than on ripe fruit, green peaches, or peach twigs. Apples may be obtained in considerable quantities from commercial orchards at thinning time and placed in cold storage for use during the winter.
2. More fruit moths may be reared from a given number of eggs placed on green apples than on ripe apples or green peaches.
3. The chief enemies encountered in the work were spiders, ants, and fruit rots. Of these, fruit rots appear to be the most important.
4. Fruit moth larvae reared in our insectary and greenhouse began to hibernate after the first week of August while those obtained after the first of September all hibernated. Hibernation may be prevented by placing stocks at 75° F. and breeding at this temperature.
5. Refrigeration of moths and eggs did not affect hibernation tendencies of the larvae.
6. Refrigeration of the larvae for short periods before spinning affected hibernation appreciably.
7. Maximum egg production was found to take place in greenhouse or other incubators where light is provided from above, and when the temperature is held at about 80° F., especially at sundown. A temperature drop in the greenhouse at sundown greatly reduced egg deposition.
8. Excessive moisture is not desirable for larvae hibernating in paper strips. It is believed that ability to hibernate or carry over the winter successfully is influenced by the quality of the food in which the larvae are reared.
9. One and one-half million fruit moth eggs were obtained in 1932.
10. The ratio of increase averaged 17 to 1 for 1931 tests. The sex ratio of reared moths appeared to be 1 to 1, or 50 per cent males.

THE LARVAL PARASITE, MACROCENTRUS ANCYLIVORUS

11. Three generations of Macrocentrus have been reared under insectary conditions at New Haven during the summer. Adults would be present almost continuously in the field after the first of June, according to these observations.
12. Other hosts have been reported and other species are discussed.
13. The life history of *Macrocentrus ancylivorus* and *Grapholitha molesta* are similar in many respects. In general the life cycle of the parasite is shorter than its host.
14. Oviposition continues under favorable conditions for about 12 days.
15. The ratio of increase averaged in our experiments 12 per female, but reached 50 per female in some tests. The rate of egg deposition is 10 to 15 daily for 10 to 14 days after they begin to lay. Thereafter oviposition becomes considerably less.
16. Hibernation does not affect the sex ratio or rate of increase of the generation emerging. Of the Macrocentrus obtained from exposures made August 5 to 6, 0.5 per cent hibernated. From then on in 1932 an increasing percentage passed the winter.
17. The sex ratio of field collected material was about 3 to 2, or 41 per cent males. Various methods were used to reduce the ratio to these figures in laboratory breeding. The most successful resulted from special mating experiments.
18. It required about 14 fruit moth eggs for every Macrocentrus adult reared in 1931.
19. Macrocentrus reared by artificial means from 1930–1933 totalled 112,983. We secured 12,000 for liberation in orchards during 1932 and 1933.
20. It is easier to secure a high percentage of parasitism using peach twigs infested with fruit moth larvae, than by using sliced apples.
21. The chief enemies are spiders, ants, and secondary parasites. Methods of control are discussed.
22. Sulfur dust applied to foliage shortened the life of Macrocentrus in cages.
23. Methods of breeding are given on page 109.

24. Twenty thousand Macrocentrus were obtained in two years from field collections in New Jersey. These were all liberated in peach orchards.

25. Field studies of the parasite indicate that it will live from year to year in the same orchard and that its presence is correlated with a general reduction of fruit infestation when the parasitism of the second brood fruit moth larvae is high.

26. It required three years in the Root and Bishop orchards to bring about the desired parasitism. The orchard of the Connecticut State College at Storrs seems to be following this course. In the Pero Orchard, parasitism developed more rapidly.

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