first, but become very conspicuous as development continues. After they are formed, the last external change occurs, in which a thin gray lip is formed at the posterior end of the scale covering. The pygidial characteristics and color are the same for the two sexes during this stage.

Male Prepupa:

After the second molt the male enters the prepupal stage. In this stage the width of the body at the anterior, middle, and posterior parts is almost the same, and the tip of the abdomen is very blunt, except for two small spines. The color is about the same as that of the larva, and by the time the growth for this stage is completed, the outlines of the antennae and wings can be seen. One hundred prepupae averaged 0.62 mm. in length and 0.40 mm. in width.

Male Pupa:

The pupa has the general shape of the adult male, and the outlines of the wings, antennae, style, and legs can be seen clearly. The color varies from a bright yellow to a yellowish brown. One hundred pupae averaged 0.72 mm. in length.

Adult Male:

The adult male is a delicate, two-winged insect, light orange-yellow in color, with a dark-brown band around the thorax, purplish-black eyes, and vestigial mouth parts. The average length of the male, including the style, was about 0.74 mm., and the wing expanse was 1.36 mm.

LIFE HISTORY AND HABITS

The Egg:

The eggs are deposited underneath the dorsal scale of the female, where they remain until they hatch. Since no observations could be made under natural conditions because of the dorsal scale, it was lifted from females that were on fruits, and observations were made on those found ovipositing. Females continued to oviposit for a time after the scale covering was removed, and under this condition the eggs were laid in chains, being lightly stuck together end to end. During the summer months the rate of oviposition was fairly rapid, as 2 eggs were laid by a female in 1 hour, and 334 crawlers were removed from an isolated female on a fruit in a 51-day period.

The length of the incubation period at various temperatures was determined from tests in which ovipositing females were held in a constant-temperature cabinet. With one group of 70 eggs held at 90° F. the first egg hatched in less than 1 hour; with a group of 37 eggs held at 80° the first egg hatched after 3 hours and the last one after 26 hours. The last egg from a group of 14 held at a mean room temperature of 67° hatched after about 48 hours.

After the egg flattens, the covering splits at the anterior end, and the larva gradually works the skin back over its body. During the summer months the hatching is very rapid, and the larva may be seen crawling before the cast skin is completely off, but during cool weather the crawler may remain partially hatched for several days.

In order to determine the minimum and maximum temperatures at which they would hatch, eggs that had been removed from ovipositing females were held in groups of 50 at different constant temperatures and left until some hatched or it was apparent that none would hatch. This procedure was repeated until the highest and lowest points at which any eggs hatched were reached. The minimum point was 53° ± 1° F. Only 1 out of 50 eggs hatched at 107.5° ± 2.5° F., and the larva died without moving after casting its skin. Other eggs appeared to flatten, preparatory to hatching, but never completed the process. No hatching occurred from a group of 50 eggs held at 110.5° ± 1.5°, and after 24 hours the eggs appeared to be shriveled.

The percentage of eggs that hatched was determined by removing them from ovipositing females, placing them on filter paper in a petri dish, and leaving them at room temperatures until they hatched or became discolored. From these tests conducted during the winter and spring months, 99 per cent of 980 eggs hatched. This high percentage of hatching was also borne out in the records taken under grove conditions, as very few discolored eggs were found under females unless signs of predators were noticed.

Active Larva:

The percentage of crawlers found alive under females ranged from 40 in March to 100 in June. In February and March, when the percentages were lowest, many predaceous mites were found under the scales with the dead crawlers. The lowest percentage of living crawlers found in any of the other months was 78. In most cases where the female had apparently completed its normal life cycle, large numbers of cast skins were found, and all larvae had emerged or settled under the old scale covering. One female was observed to have 14 immature scales under it. No accurate method was found for determining what percentage of the crawlers under an ovipositing female emerge. From the foregoing counts, however, the indication is that the dorsal scale of the ovipositing female does not hinder emergence, since very few females were found with large numbers of dead crawlers under them unless some signs of predaceous enemies were evident.

The distance traveled by active larvae was determined in tests made in the screened insectary. Crawlers were placed on smooth paper and on grapefruits, their movements were traced with a pencil, and the distances traveled were measured with a map measurer. From observations made over 2-hour periods it was found that the average distance traveled by six crawlers on smooth paper was 38 inches when the mean temperature was 86° F., and by four crawlers, 20.6 inches at a mean temperature of 69°. All crawlers were still alive at the end of the 2-hour periods. The distances five crawlers traveled on a grapefruit ranged from 1.5 to 9 inches, and the time required before settling ranged from 15 minutes to 1 hour.

In an experiment where larvae were placed on dry sandy soil they had great difficulty in traveling. Two hours was the minimum time observed for a crawler to travel from the center to the edge of a 6-inch circle of such soil. The minimum temperature at which crawlers made any

effort to move about was 55°. Movement was very slow until the temperature reached 60°.

The ability of a larva to live without food on slightly moistened filter paper ranged from 6 to 13 days, as compared with 3 to 4 days on dry filter paper. Crawlers that were transferred to leaves after living for 4 days on slightly moistened filter paper were able to settle, but those kept on the paper longer were not. Living crawlers were found up to the 25th day on leaves picked during the winter months and placed in petri dishes without additional moisture. By this time all ovipositing females had died and all eggs had hatched.

Observations made during this study indicated that crawlers will settle as readily on leaves as on fruits, and will settle on leaves or fruits of any age, with the exception of very immature fruits. Some scales were found on green wood, but rarely unless the infestation was extremely heavy. No scales were found on gray wood.

A larva, upon being placed on a leaf, usually moves over both the upper and lower surfaces. After this activity has continued several minutes, it moves very slowly over a selected area and inserts its mouth parts. The body moves considerably while the mouth parts are being inserted. The first waxlike threads of the scale covering appear on the posterior end of the body, and as they are being secreted the body is slowly rotated, the mouth parts being used as a pivot, until it is turned completely around, and then the movement is retraced. About 30 minutes is required for a scale to make a turn of 360°. This rotating continues as long as the body can be seen. During the movement some contractions of the body and movement of the legs are visible. The first waxy covering is easily removed; from one scale six coverings were removed as soon as each was completed, before the scale died. After the larva is completely covered with the wax, it is considered to be in the white-cap stage. At this stage the covering is round and the sides are vertical. A thin gray ring is then formed around this central nipple. From data secured during the summer months, when the temperature ranged from 72° to 91° F., the average time from emergence to settling was 95 minutes, from settling until the white-cap stage was 100 minutes, and the time spent in the white-cap stage was 21 hours and 20 minutes.

Data on the percentage of the crawlers that settled were obtained by placing eggs in gelatin cylinders on fruits at room temperatures and leaving them until they hatched and the crawlers settled. Under these conditions 76.5 percent settled of 443 larvae that were observed. Wind, rain, predaceous enemies, and extreme temperatures are some of the hazards encountered in settling under grove conditions.

First Instar:

Artificial infestations were started in 1939 for a study on the length of time the scale spends in each instar under grove conditions. The infestations were made by fastening leaves heavily infested with the Florida red scale to uninfested leaves and fruits. In warm weather many crawlers had transferred to the clean surfaces within 2 days, and the leaves that were the source of infestation were removed; in cool weather the leaves

were left on for about 4 days. The newly settled larvae were then circled with India ink for identification. Each individual was examined every 2 days when possible, and its stage of development recorded. A hygrothermograph was operated in the screened insectary in the grove for temperature and humidity records during this study, and the data on the duration of each stage of development were correlated with temperature.

During the first part of this work new infestations were started monthly, but later they were started twice each month to obtain more data. In the 64 infestations made over a 3-year period 12,603 scales were marked for study, but only 4,942 completed the first instar. Some were removed for microscopic examinations, and some were destroyed by premature dropping of leaves from frequent handling. When these had been deducted, mortality in the remaining larvae ranged from 76 percent in December to 37 percent in September.

From data from these infestations it was possible to calculate the effect of seasonal variations in temperature upon duration of development of the first instar. The time required for development for each infestation was inverted to obtain the rate of development. These rates were correlated with the temperature, the regression equation being $Y = -75.6246 + 1.6633X$, and the correlation coefficient $r = 0.9526$. The rates estimated from the regression equation were inverted to give estimated times of development which, when plotted, gave a smooth hyperbolic curve (Fig. 1).

The length of the instar was calculated from the time the infestation was made until the scale was considered to be through the first molt.

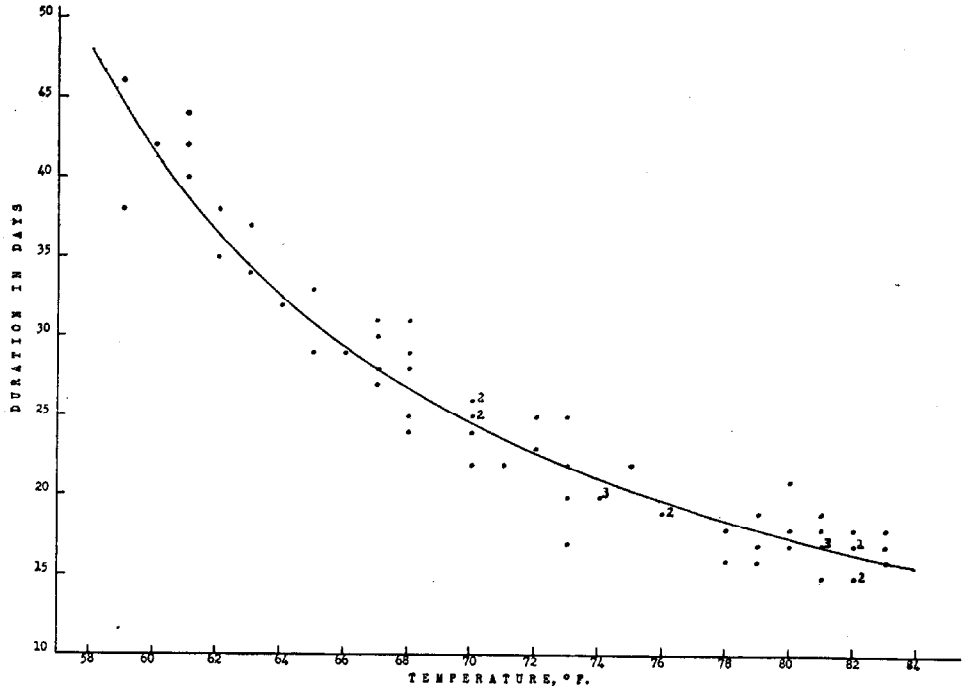

Figure 1.—Relation between temperature and the time required for development of the first instar of the Florida red scale.

Considerable variation in development occurred at the same temperatures, but many factors could have caused this. The time required for completion of the instar ranged from 46 days at 59° F. to 15 days at 82°. The optimum temperature for development was between 78° and 83°, but there was little difference in the rate of development between these points, although below 78° the time required for development was increased.

Second-Instar Female:

After the scales had completed the first molt, examinations were continued to determine the length of the second instar. From these infestations 3,325 females were observed, of which 877 completed the second instar. Owing to the high mortality from November through March, female scales were able to complete the second instar in only 51 of 64 infestations. The development of the male and female differs after the first instar, and data on only the females are included in Figure 2, which gives the number of days required for the completion of the second instar correlated with the mean temperatures for the period. The curved line represents the expected time required for completion of the instar at any given mean temperature between 61° and 83° F. This line was plotted in the same way as the one for the first instar, the regression equation in this case being $Y = -101.1596 + 2.1046X$ and the correlation coefficient $r = 0.9258$.

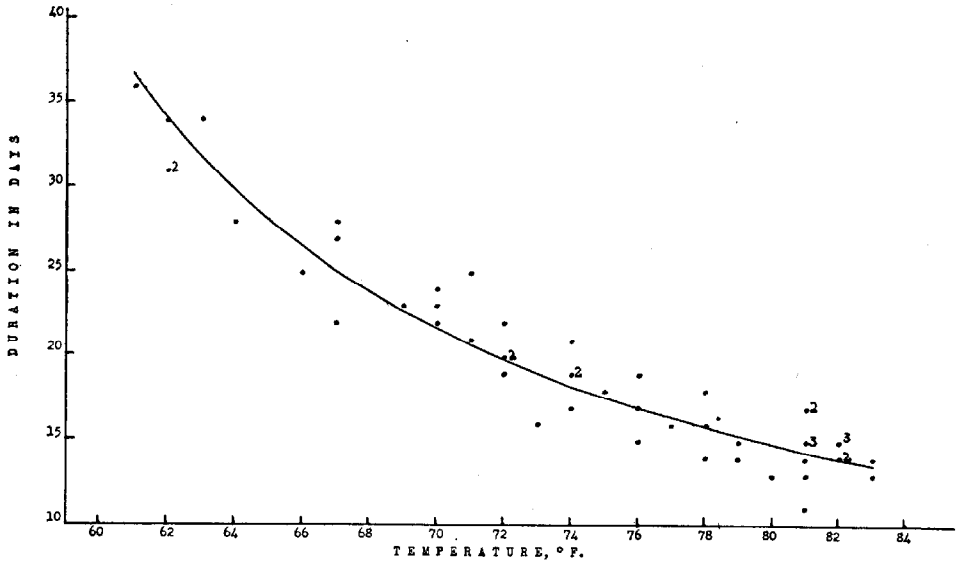

Figure 2.—Relation between temperature and the time required for development of the second instar of the female Florida red scale.

The length of the instar ranged from 36 days at 61° F. to 11 days at 81°. The variation between the actual number of days recorded and the expected number of days was not so great in this instar as it was in the first. As in the first instar, the optimum temperature for development was between 78° and 83°. It was found that temperature affected the development of the second instar less than it did the first, and that the greatest difference in time occurred at 69°.

The natural mortality during each month, computed as for the first instar, ranged from 96 percent in March to 51 percent in September. It varied considerably from month to month, but was obviously higher during the winter months. Natural mortality was unusually high in the grove where the work was conducted. From infestations made in the fall and winter months, when the parasites were the most effective, very few of the marked scales reached maturity.

During January, February, and March 1942, examinations were made to secure additional information on the number of parasitized second-instar females. Each month 50 leaves picked at random from 10 trees in the laboratory grove were examined under a binocular microscope. Of 5,039 second-instar females examined, 40, 50, and 55 percent were found with parasites in the respective months. The percentage of living scales ranged from 13 in January to 3 in March. A scale was considered to be parasitized if the parasite's body or any portion of it was found in the scale's body, or if the dorsal scale showed the characteristic round emergence hole with the shell-like body of the scale under it. Most such females had entered the second molt before the parasite had developed enough to kill them, and very few ever completed the molt.

Adult Female:

Very little definite proof has been obtained on how or when fertilization occurs, but it is believed to occur at night shortly after the female completes the second molt, as the males of the same age emerge at this time. Inasmuch as Schweig and Grunberg *(6)* proved that fertilization by the male is necessary for reproduction, no experiments were made along this line, although additional evidence was obtained in a few cases when females isolated for reproduction records failed to reproduce, evidently having been isolated before fertilization occurred. The time from the completion of the second molt until the first eggs were deposited ranged from 2 to 4 weeks; the oviposition period ranged from 1 to 8 weeks.

Reproduction records were obtained in a screened insectary from adult females isolated in gelatin cylinders on leaves of potted citrus plants and on fruits picked from trees in the grove. If crawlers or settled larvae were found in a cylinder within 3 days after isolation in summer, or within 5 days in winter, the female was discarded because of the possibility that it was already reproducing when isolated. The remaining cylinders were examined at intervals, and all newly settled scales or active larvae were counted and removed. When no crawlers were found in a cylinder for several days, the female scale was turned over, and the number of scales that had settled under it was recorded. In this way the total number of crawlers produced by each female was obtained.

The number of crawlers produced by each of 30 females on fruits ranged from 32 to 334, with an average of 145; the number produced by 25 females isolated on leaves ranged from 21 to 156, with an average of 80. Not only did the females isolated on fruits produce more young than did those on leaves, but they did so in a shorter period of time. The total number of crawlers produced was the same in cool and warm weather. The minimum time from infestation to oviposition was 45 days and the

maximum was 153, the latter occurring during abnormally low temperatures. Very few of the females deposited all their eggs, as some could still be seen in their bodies after death.

Immature Stages of the Male:

Inasmuch as temperature proved to be the main factor that determined the rate of development of the immature stages of the female, it was assumed that the same would be true of the male scale. However, one infestation was made in 1940 to secure data on the changes that occur in the male and on the time required for the completion of each change. On August 3, 840 scales on the upper surfaces of leaves were marked for identification. Every 2 to 4 days after the first molt was completed about 15 males were examined to determine the stage of development.

It was found that about 5 days after completion of the first molt the eye spots could be seen, 5 additional days were required for the lip to be formed on the dorsal scale, and after 3 more days the prepupal stage was reached. The prepupal and pupal stages so overlapped that it was difficult to determine their length, but each is very short, as winged adults were found 15 days after completion of the first molt. The body of the male does not stick to the dorsal scale in any molt except the first, and the cast skins of the second, third, and fourth molts are pushed out under the lip of the dorsal scale.

Adult Male:

To determine the duration of the developmental period of the male — that is, the time from artificial infestation to the end of the pupal stage — the dorsal scales of many individuals were carefully removed. When a winged adult was found, the time from infestation to that date was calculated. If prepupae or pupae were found, they were placed in petri dishes on moistened filter paper to complete their transformation into winged adult males, and then the number of days from infestation to the time the last molt was completed was calculated. The time required for development was correlated with the mean temperature for each infestation (Fig. 3). The curved line, which represents the estimated rate of growth, was calculated as for the first- and second-instar females, the regression equation in this case being $Y = -49.2057 + 1.0164X$, and the correlation coefficient $r = 0.9798$. In the examinations 106 winged males were found, and the period of development ranged from 78 days at 61° F. to 28 days at 83°.

Some variation in the rate of development at the same temperature occurred, but this was expected as the numbers were small and the dates on which males were found could have been either the earliest or latest days for completion of development and not the average. It was found, however, that the calculated rate of development of the male corresponded closely with the calculated time required for the female to complete the second molt at the same temperatures. At no temperature was the variation greater than 3 days. After a male emerges, its life is very short, as no food is taken. The longest period that one was kept alive was 4 days.

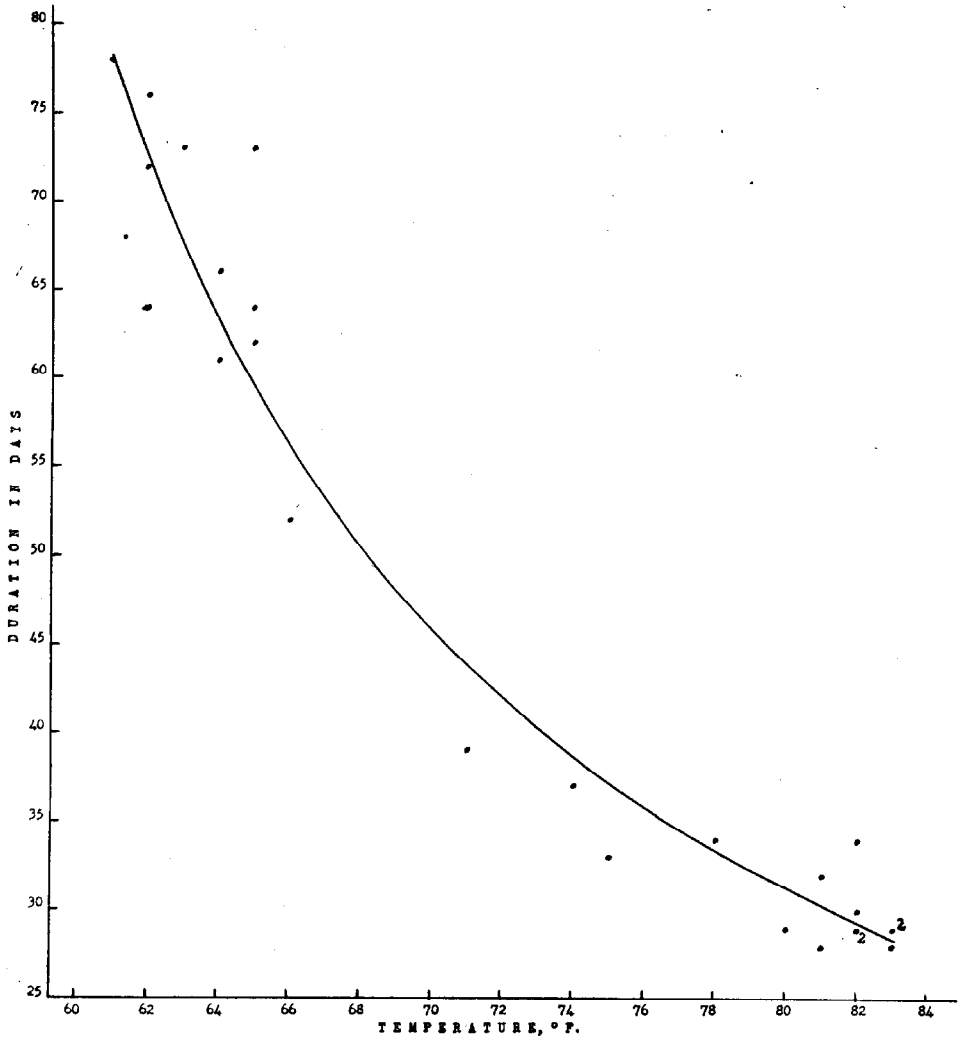

Figure 3.—Relation between temperature and the time required for the development of the male Florida red scale.

Number of Generations a Year:

To determine whether an adult female has reached the ovipositing period, the dorsal scale must be lifted. After females of the artificial infestations reached the adult stage, such examinations were made at irregular intervals, and when a female that had apparently just entered the oviposition period was found, the time that had elapsed since the infestation date was recorded. It was found that five or six generations would occur over a period of 12 months at a mean temperature of 74° F. Schweig and Grunberg *(6)* state that three to four generations were produced in Palestine at a mean yearly temperature of 19.3° C. (67° F.) and five generations at a mean temperature of 22.5° C. (73° F.).

Ratio of Males to Females:

Each month when the seasonal-history counts discussed in the following section were made, the males and females were recorded separate-

ly if their development had reached a point where the sexes could be distinguished. Of the 15,738 scales so recorded during a 12-month period, 59 percent were females, the range being from 52 to 68 percent.

Distribution of Males and Females on Leaf Surfaces:

From the same seasonal-history counts records were also kept of the numbers of males and females found on the upper and lower surfaces of the leaves. It was found that 96 percent of the males and 13 percent of the females were on the upper side of the leaves. It was thought that light or gravity might be factors influencing this distribution. If this were true, scales that settle in the absence of light should have an equal distribution. In the case of gravity, the distribution of the sex should be reversed if the leaf surfaces were reversed.

To determine the influence of absence of light on the distribution, infestations were made on potted citrus plants in a photographic dark room by clipping infested leaves onto the clean leaves of the plants, just as was done in making the artificial infestations in the grove. Several days later the clipped-on leaves were removed, but the plants were left in the dark for an additional day to give all the crawlers time to settle before the plants were removed from the dark room. The scales were then allowed to develop until their sex could be determined, and counts were made of the males and females on the upper and lower surfaces of the leaves. To determine the effect of gravity on the distribution, potted citrus plants were suspended in an inverted positon and infested. Table 1 gives the results of these experiments.

TABLE 1.—DISTRIBUTION OF MALES AND FEMALES OF THE FLORIDA RED SCALE FOUND ON UPPER SURFACE OF CITRUS LEAVES.

Date of Infestation	Males (Percent)	Females (Percent)
In the Absence of Light		
1940		
May	90	58
June	54	40
1942		
May	83	50
	77	68
	78	35
Average	76	50
On Inverted Plants, to Test Effect of Gravity		
1942		
May	56	34
June	58	45
Average	57	40

In the experiments in which the crawlers settled in the absence of light, the females were evenly distributed between the two surfaces, whereas 76 percent of the males settled on the upper leaf surfaces. In the experiments to determine the effect of gravity, a fairly even distribution was secured for each sex. The experiments indicated that light is one of the most important factors influencing the distribution of the females, but no definite indications were secured for the male although, while it seems that both light and gravity affect their distribution, evidently other factors also exert influence.

SEASONAL HISTORY

Once each month from April 1942 through March 1943 a sample of 5 leaves was picked at random from each of 80 orange trees, and the numbers of scales in each stage were recorded. Table 2 gives the number of living scales and of ovipositing females found at each examination.

TABLE 2.—SEASONAL DISTRIBUTION OF THE FLORIDA RED SCALE ON CITRUS.

Date of Examination	Number of Scales on 400 Leaves	
	Living	Ovipositing
1942		
April	1,071	37
May	868	14
June	316	13
July	788	31
August	1,413	42
September	1,743	38
October	1,286	19
November	620	17
December	538	11
1943		
January	378	13
February	309	12
March	216	6

The number of living scales appears to be unusually high in April, but no explanation can be given for this. The number decreased in May and June, and this is believed to have been caused partially by the falling of the old, infested leaves. In June it was impossible to secure a randomized sample of fully matured leaves, because there was so much new growth, and probably the distribution of the scales was not general over the new growth. The number of living scales increased from June to September, when the peak was reached, and thereafter decreased each month.

The number of ovipositing females followed the same trend as the number of living scales, except that the peak was reached in August.

The percentage of parasitized scales was calculated from the number of settled scales, exclusive of those in the first instar, since only two first-instar scales were found with visible parasites in them. The percentage of