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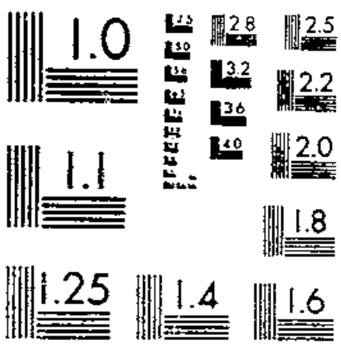

MICROCOPY RESOLUTION TEST CHART
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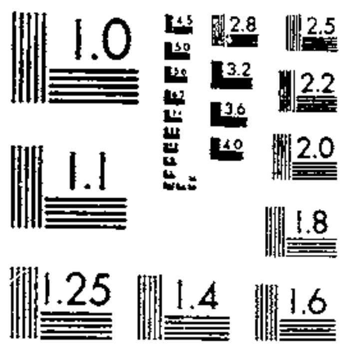

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Life History of the Wireworm Melanotus Longulus (Lec.) in Southern California[1,2]

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RELATIVE IMPORTANCE OF THIS WIREWORM

The wireworm *Melanotus longulus* (Lec.) [3] ranks next to the sugar-beet wireworm (*Limonius californicus Mann.*) (*8*)[4] as a serious pest of vegetable and grain crops in southern California. The larvae of this species damage germinating seed, either by eating the entire contents or by destroying the germ. The larger seeds, especially all

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[2] Acknowledgments are due R. E. Campbell, under whose direction this work was conducted; K. D. Sloop for assistance in the rearing work during 1932 and 1933. Acknowledgment is also due Mary F. Benson for the drawings of the larval, pupal, and adult stages. The authors are especially indebted to M. C. Lane, in charge of wireworm investigations at the Walla Walla, Wash., laboratory of this Division, and to H. P. Lanchester, of his staff, for preparing the descriptions of the larval, pupal, and adult stages of *Melanotus longulus* (Lec.).

[3] Order Coleoptera, family Elateridae.

[4] Italic numbers in parentheses refer to Literature Cited, p. 29.

varieties of beans, corn, melons, and wheat, are most susceptible to attack. Roots of growing plants may be eaten off or the larvae may burrow in and up the center of the stem, causing the plant to wither and eventually fall over. Older bean plants often withstand this form of attack, but the quality and quantity of the beans produced is lowered, owing to the weakened condition of the plants. Many lima bean growers whose fields are heavily infested are compelled to replant all or portions of their fields each year, and occasionally these second plantings are badly damaged and the yields greatly reduced. Growers experience another large annual monetary loss by the planting of additional seed. Years ago from 50 to 70 pounds of lima beans were planted per acre, but now, because of greater damage, this quantity has been increased to 90 to 110 pounds per acre. The larvae damage young sugar beets by severing the taproots and also feed on the older beets up to harvesttime. Potato seed pieces may be injured severely and later the tubers may be burrowed into, rendering them unfit for marketing. The larvae also feed on the stems and roots of tomatoes and cruciferous crops, causing considerable damage.

Melanotus longulus may be found in all types of soil, both irrigated and nonirrigated. It often attacks lima beans on steep hillsides where the soil is extremely dry during the summer and early fall months. Siftings made in irrigated beanfields during the spring of 1932 and 1933 in Ventura County showed that an average of 24 percent of the larvae recovered were *M. longulus* and the remainder were *Limonius californicus*.

Because of the importance of *Melanotus longulus*, life-history studies were begun in 1931 at the Alhambra, Calif., laboratory of the Bureau of Entomology and Plant Quarantine of the United States Department of Agriculture and were continued during the period in which the life-history studies (*8*) of the sugar-beet wireworm were conducted, up to 1937. A report of these investigations is presented in this bulletin.

DESCRIPTIONS OF THE STAGES[5]

THE ADULT

(Fig. 1, *D*)

MALE

Length 8–12 mm.; width 2.2–3.2 mm. Form elongate parallel, integument moderately shining; color above brown to dark red-brown, beneath very little lighter, but antennae and legs lighter than rest of body. Vestiture brownish gray, moderately long above, longer beneath, but not obscuring shiny surface.

Head quadrate, coarsely umbilicately punctured; frons slightly convex at vertex to flat between eyes, and somewhat concave near clypeal margin, which is slightly reflexed and produced over nasale; nasale narrowed by deep lateral pits which are independent of antennal impressions; antennae only slightly longer than pronotum at posterior lateral angles, second and third segments of similar shape, third only slightly longer, second and third together about same length as fourth, which is triangular and more setose, fourth to tenth triangular and setose, last segment oblong-oval, three times as long as wide; mandibles with deep elongate pits near base.

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[5] Descriptions of larva, pupa, and adult by Merton C. Lane and Horace P. Lanchester, of the Division of Truck Crop and Garden Insect Investigations, Bureau of Entomology and Plant Quarantine.

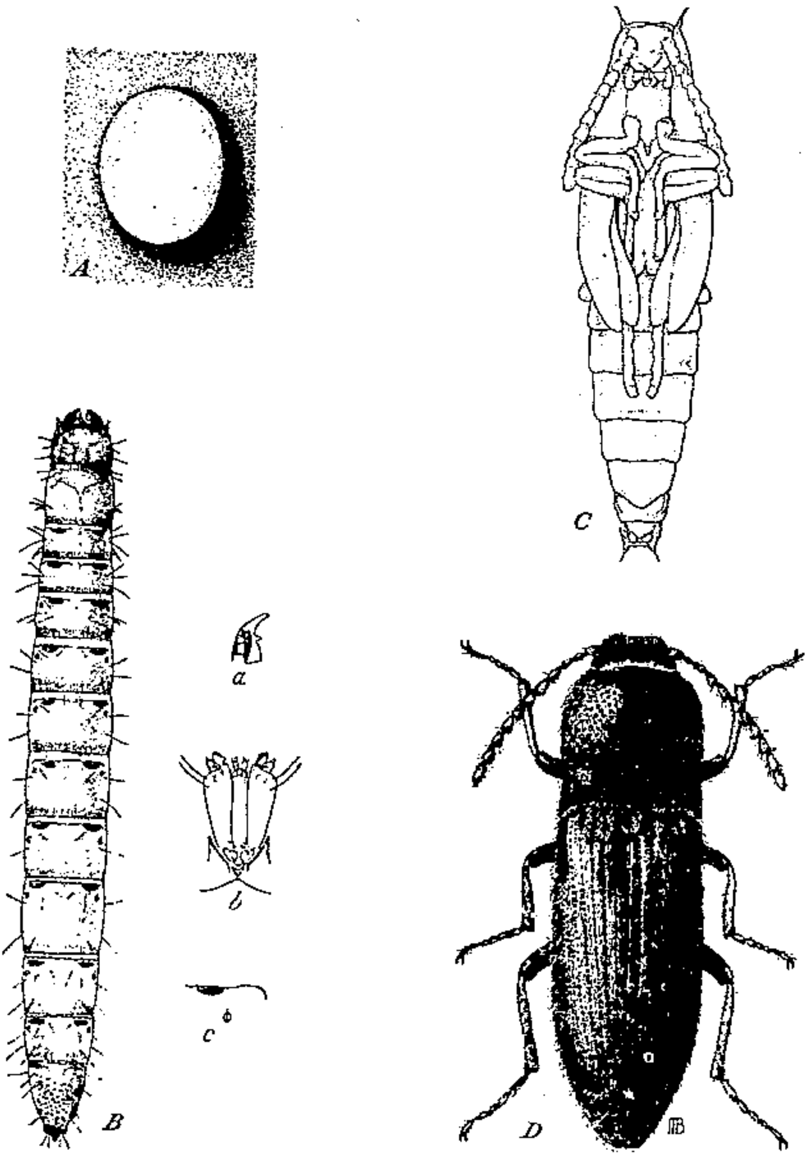

FIGURE 1.—The wireworm *Melanotus longulus*. *A*, egg, ×22. *B*, larva, ×6: *a*, Mandible, dorsal view; *b*, head capsule, ventral view; *c*, spiracle. *C*, pupa, ×5. *D*, adult, ×6.

Pronotum about as wide as long, widest posteriorly, sides usually straight, either parallel or slightly narrowing from near posterior angles to one-fourth from anterior margin, then arcuate to anterior angles; posterior angles straight, produced and slightly divergent, with strong carina extending anteriorly about one-fourth length of pronotum, slightly divergent inward from margin, basal median impression moderate and short, sulci of basal margin evident and parallel; surface moderately, densely, shallowly umbilicate-punctate, punctures less dense on summit, more so on sides. Scutellum flat, slightly oblong, densely punctate and pubescent as on summit of pronotum.

Elytra as wide as pronotum at posterior angles and about three times as long, sides parallel to posterior third, slightly arcuate to apices, which are rounded; striae shallow, with moderately deep, oblong punctures, intervals flat, with two irregular rows of fine punctures.

Propleura densely, deeply punctate with oblong punctures; sternopleural plate excavated and flared in front, grooved nearly one-half distance to procoxae; posterior margin of propleurae with rectangular notch near produced hind angles, which are usually rectangular. Prosternum moderately densely and deeply punctuate, except prosternal lobe, which is prominent and nearly impunctate; mucro flat and punctate between coxae. Metasternum and abdomen moderately finely, sparsely punctate, except on sides, where punctures become deeper and oblong, and on last segment, which is deeply, densely punctate.

FEMALE

Length 10–13 mm., width 2.8–3.8 mm. Differing very little from male in color, and only slightly larger; thorax somewhat more convex in general and with sides more rounded in most specimens; antennae slightly shorter than thorax, middle segments shorter than in male and wholly lacking the erect pubescence on inner margin of fourth to eleventh segments which is always present in males and can be used to distinguish sexes in this genus.

LeConte (*4*) described this species in 1853 from specimens collected near San Diego, Calif., the type now being in the Museum of Comparative Zoology, Cambridge, Mass. Other material examined was all from southern California, as follows: Ventura, April and May (Stone); Temple, March and April (Stone); Santa Ana, April; Palm Springs, May; Burbank, Pasadena, May; Victorville, June; Providence Mountains, San Bernardino County, April; Avalon, June; Warners Springs, May; and Indio, March. Specimens from Arizona and southern Utah in the Lane collection are probably this species, the only difference being the smaller size and lighter-brown color.

In 1861 LeConte (*5*) also described *Melanotus variolatus* from specimens collected at San Pedro, Calif. (Bache). The type of this species, also in the Museum of Comparative Zoology, is a female, and is probably the female of *M. longulus*. *M. oregonensis*, described by LeConte (*4*) in 1853 from Oregon, will have to be considered a distinct species, owing to differences in distribution and in the male genital organs. The aedeagus of the type male is distinctly different from that of *M. longulus*, the outer angles of the lateral lobes in *M. oregonensis* being elongate arcuate without semblance of angulation, with the middle lobe slightly broader and blunter at the apex.

No specimen of typical *Melanotus oregonensis* has been seen from the southern California area where *M. longulus* is common. On the other hand, *M. longulus* apparently does not occur north of Tejon Pass, Kern County, Calif., except possibly along the coast. *M. oregonensis* is found in both the San Joaquin and the Sacramento Valleys northward through Oregon and Washington, and eastward into Idaho and northern Utah. Individuals of this species vary exceedingly in size, color, and form, but the differences appear to be only those of degree due to environmental factors of food and climate.

THE EGG

(Fig. 1, *A*)

Egg grayish white, becoming darker as the embryo develops; ellipso-cylindrical and with the ends broadly rounded; eggshell smooth, elastic, and not easily ruptured. Length 0.49–0.54 mm., average 0.51 mm.; width 0.36–0.39 mm., average 0.37 mm. (Average of 15 measurements.)

THE LARVA

(Fig. 1, *B*)

Form slender, cylindrical, nearly uniform in width; color yellow-brown, darker at both tips, shiny. Segmentation apparent as transverse striations; legs seldom visible from above; mouth parts, antennae, or body armature not especially evident.

Head capsule flattened, blunt, with single-pointed nasal projection; mandibles with both distal and proximal lobes, the latter small; stipites widely separated by postlabium throughout length; antennae reduced, last segment minute; eyes absent.

Body sclerotization uniform; the slender, parallel-sided laterotergite united to the tergite by a suture, separated from the sternite by a narrow membranous ribbon; paired secondary atrial chambers of spiracles visible, small, dark, and located in tergite near anterolateral corner; on each segment a transverse dark line, becoming somewhat scalloped on posterior segments, encircling body anterior to spiracles, not evident on laterotergites; on each side at a distance from lateral margin approximately equal to width of laterotergite and immediately posterior to the transverse line a small, dark, pigmented area with 6 to 10 longitudinal ridges; these dark areas increasing in size on posterior segments and on ninth abdominal segment enlarged to nearly twice the number of ridges; a narrow longitudinal groove in the integument extending from lateral end of each area two-thirds of distance to striated portion of segment, scarcely apparent in any thoracic segment.

Coxae erect, protruding; nearly as heavily armed posteriorly as anteriorly; legs moderate to small, distal segments in repose lying against lateral surface of coxae and entirely hidden from above.

Ninth abdominal segment slightly dorsoventrally depressed; sclerotization heavier than on other segments except head, and roughest of any; four longitudinal, nearly parallel grooves on dorsal surface extending posteriorly from near transverse line approximately one-half distance to end of segment, two arising near middles of extended dark areas of ridges, and two near mesal ends of same areas; lateral margins uniformly narrowed, less suddenly constricted anterior to lateral angles of tip than in specimens of *oregonensis* and *communis* (Gyll.). Tip blunt, angles not acute, even in the middle angle or point seldom less than a right angle in large larvae, younger stages more acutely angled; dorsal surface immediately anterior to three-angled tip frequently convex, seldom with a longitudinal median groove.

The larvae of *Melanotus oregonensis* from Walla Walla, Wash., appear to be more coarsely roughened on the ninth abdominal segment than *M. longulus*, also more depressed and grooved anterior to the tip, more restricted laterally anterior to the lateral angles, and with all angles, especially the median one, more acute. The larva of *M. communis*, as illustrated by J. A. Hyslop in unpublished drawings, differs from that of *M. longulus* by having a blunter, shorter ninth abdominal segment, less narrowed to the shoulders of the tip. Undetermined *Melanotus* larvae from North Carolina show forms with the ninth abdominal segment blunter and forms with this segment much narrower than in *M. longulus*.

THE PUPA

(Fig. 1, *C*)

The pupa of *Melanotus longulus* is free or exarate, similar in appearance to the adult but with the appendages immovable and visible, as though through transparent coverings. Although a distinct stage, the pupa shows gradual changes from the pure white, waxy condition of its first appearance to a darkened, hardened condition just prior to its transformation to adult. This darkening first appears in the tips of the mandibles, in the shading of the eyes as viewed through the shield of the pronotum, and in the tarsal claws. The four pairs of pupal spines appear to be movable and somewhat variable as to the direction in which they point.

Measurements variable, slightly in excess of those of resultant adult. Nearly pure white during development, darker prior to transformation to adult. Head withdrawn into prothorax to base of antennae, eyes covered; antennae resting against propleurae, approximately as long as in adult; mouth parts exserted and developing gradually. Prothorax with pronotum, propleurae, and prosternum distinguishable. Pronotum armed with three pairs of large, elongate, and pointed spines which seem to be characteristic of the pupal stage in the Elateridae; anterior pair near anterior margin of pronotum and dorsad of eyes, lateral pair near tips of posterolateral angles, and medial pair in angles formed by posterior margin and medial basal groove.

Legs normal, held as when feigning death in the adult, first two pairs visible, protarsi over mesocoxae and reaching mesotarsi, metalegs hidden by wings except for tarsi. Mesothorax and metathorax visible dorsally, partially hidden ventrally by legs and wings, completely hidden laterally by wings. Scutellum evident dorsally in posterior two-thirds of mesothorax, oval. Elytra and wings clasping body closely and extending posteriorly and ventrally; wings nearly hidden by elytra except near point of attachment and near tips, which extend beyond elytra nearly to meet just posterior to metasternum.

Abdomen extended, with nine visible segments dorsally, the first seven bearing paired spiracles, the ninth with another pair of pupal spines at extreme posterolateral angles as on pronotum. Only the last seven abdominal segments visible ventrally; fifth visible ventral segment evident as last visible ventral segment of adult; last segment bearing ventrally the buds of the genitalia—two protuberances for the female and three for the male.

REARING TECHNIQUE

Rearing experiments were carried on in tile cages out of doors and in the laboratory in a well-insulated cement basement where temperatures closely approximated prevailing outdoor temperatures below the surface. Immediately upon hatching, the larvae were confined individually in 2-ounce salve cans containing moist sifted soil (12 to 16 percent by weight) and 10 kernels of moist wheat. At monthly intervals the soil in the salve cans was changed and the required amount of moistened wheat was added. When the larvae reached the prepupal stage, as indicated by enlarged middle segments, shortening of the body, and inactivity, they were placed in small depressions made by pressing the thumb into moistened soil in the salve can. Pupae were confined in the same manner. Examination of these prepupae or pupae was then made daily until pupation or adult transformation occurred. The dates of occurrence of these stages, along with the date of adult transformation, was written on the lids of the salve cans.

Newly transformed adults were provided with an artificial pupal cell constructed simply by pressing the point of a pencil into the firmly packed moist soil with which the cans were filled. The cell opening was then covered over with a small amount of soil so as to retard drying out of the cell wall and to discourage movement of the adult to the surface, where it would be more susceptible to attack by fungi forming underneath the salve-can lid. Adults confined in this manner passed the winter with only light mortality.

In rearing larvae out of doors, two unglazed drain tiles (6 inches in diameter and 12 inches long) were cemented together end to end and buried vertically in a trench 22 inches deep. This allowed 2 inches of the top to remain above the soil surface so that screen cages could be attached, and also prevented debris from washing in after rains or irrigations. After installation of the cages, the soil was replaced and firmly packed down. To prevent escape of the larvae, the bottom of the tiles was filled with a half-inch layer of plaster of paris and, after drying, the cages were filled with sifted soil previously fumigated with carbon disulfide.

In general, 25 newly hatched larvae were placed in each cage near the 12-inch depth; then a small amount of corn was added at different levels as the soil was replaced. The larvae were fed monthly from February to October and at 6-week intervals during the winter months, when larval activity had lessened. Screen cages were installed during the flight period so as to prevent possible oviposition by other elaterids. The moisture content of the soil was maintained as near the optimum as possible by irrigations at various intervals throughout the year.

Temperature records at the 4-, 8-, and 12-inch depths were obtained by using recording thermometers of the 2-pen type, and standard Weather Bureau hydrothermographs were used to record the temperature and humidity in the basement and out of doors. Additional details as to the preparation of soil for oviposition, method of obtaining eggs, and construction of outdoor oviposition cages are given in an earlier publication (7).

Tenhet (*10*) in 1939 criticized the salve-can and tile-cage methods of rearing wireworms and recommended earthenware flowerpots (probably 6 by 8 inches), which he used for rearing larvae of *Horistonotus uhlerii* Horn. The writers realize that both the salve-can and tile-cage methods of rearing wireworms have their disadvantages. In the former the larvae do not have sufficient space to orient themselves either vertically or laterally when subjected to temperature or moisture changes, and when the latter method is used the mortality is so great through cannibalism that the original series must contain at least 2,000 to 3,000 larvae if significant life-history data are to be obtained on the individuals completing their life cycles after 3, 4, or 5 years. The flowerpot type of cage could not be used because during the summer and winter the larvae of this species burrow deeper than the ordinary depth of flowerpots and, if so confined, would be subjected to higher temperatures, and possibly their rate of development would be accelerated as a result.

LIFE-HISTORY STUDIES

The Egg

DEPTH IN SOIL AND PLACE OF OVIPOSITION

The depth of oviposition was determined by using 3- by 12-inch tile cages containing loosely packed, moist 60-mesh soil and 10 adult pairs of wireworms in each cage. These cages, after being provided with suitable screen tops, were buried out of doors on May 20, 1931. Examination on June 15 consisted of removing and washing through a 60-mesh sieve each square inch of soil to a depth of 4 inches, and then carefully counting the eggs in each sample.

On the basis of results obtained under cage conditions, females of this species deposited 72 percent of their eggs in the first (top) inch of soil, 18 percent in the second inch, 7 percent in the third, and 3 percent in the fourth. There was no opportunity to conduct field tests to verify these findings.

As adults in the field emerge during April and May, at a time when the fields are being cultivated extensively and when optimum soil moisture prevails, the females should have no difficulty in selecting suitable places for oviposition. Whether the presence of vegetation influences the selection of oviposition sites is not definitely known. There may or may not be vegetation present, for the date of planting, in the case of lima beans, may be anywhere between April 15 and June 1, depending on location, temperature, and soil moisture.

INCUBATION PERIOD

The time required for the incubation of eggs of *Melanotus longulus* depends largely on temperature. Optimum moisture is also important, because if the soil is too dry, the eggs may become desiccated, and if it is overly moist, fungi become common and sometimes kill an entire group of eggs.

To obtain incubation records, the eggs were removed from the oviposition cage on the day following their deposition and were placed in salve cans half filled with moist 60-mesh soil. Each can contained from 10 to 20 eggs a short distance apart. A small quantity of soil was then added as a precautionary measure against fungi, which usually start growth underneath the salve-can lid. As time for hatching approached, the soil was removed daily, washed through a 60-mesh screen, and the larvae, if present, were placed in individual containers. The unhatched eggs were returned to the salve cans and examined each day thereafter until all hatching had ceased.

The incubation data for 1932 were based on 1,456 eggs which were deposited in the period April 12 to May 19 and hatched between May 13 and June 18. Temperatures in the basement during April and May were fairly uniform, varying only 1° F. As a result, there was only a 2-day difference in the mean period of incubation in these months. The maximum incubation period was 38 days in April and the minimum was 26 days in May. The seasonal average was 31.7 days.

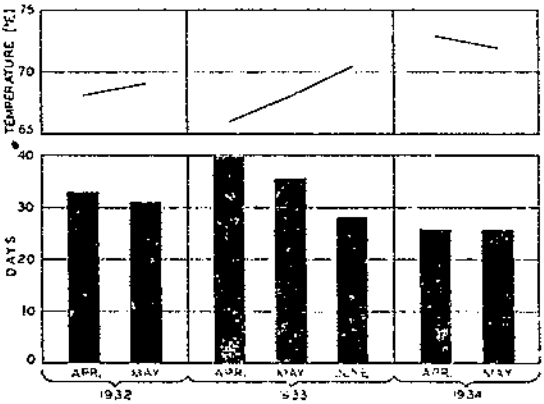

FIGURE 2.—Length of the incubation period of eggs of *Melanotus longulus* in salve cans, as compared with the mean basement temperature at the Alhambra, Calif., laboratory, 1932–34.

In 1933 hatching began on June 2 and continued until July 6, the records being based on 1,700 eggs laid between April 23 and June 8. Owing to low basement temperatures in April and May, both the maximum and average incubation periods were the longest recorded during these studies. The maximum was 45 days; and the average, 39.5 days, was recorded for eggs deposited in April. Higher temperatures prevailed in the basement during June and, as a result, the period of incubation was shortened to an average of 27.0 days.

The records of incubation for 1934 were based on 168 eggs, laid between April 10 and May 20 and hatched in the period May 15 to June 17. Temperatures in the basement during incubation were higher in 1934 than in previous years (average, 72.5° F.), and in consequence the average incubation period was shortened to 25.5 days. The shortest incubation period recorded was 25 days. Figure 2 shows the effect of temperature on the duration of the incubation period during 1932, 1933, and 1934.

THE LARVA

DEVELOPMENTAL PERIOD

The larvae of *Melanotus longulus* were reared in salve cans in an insulated basement which responded very slowly to changes in temperature. Conditions here approximate somewhat the natural environment of the insect. The temperatures in the basement during the period of these studies (1931–37) ranged from a minimum of 46° F. in December and January to 88° in July, August, or September. Average yearly basement temperatures ranged from 67.0° in 1931 to 69.9° in 1934. Soil temperatures out of doors at the 12-inch depth reached the maximum of 88° on July 26, 29, and 16 in 1931, 1932, and 1935, respectively. Maximums of 87° were reached from August 15 to 18, 1933, and on July 31, 1934. The lowest minimum soil temperature at the 12-inch depth was 41° on December 15, 1931. Daily minimums of 43°, 45°, 51°, 48°, and 44° were recorded in January of the successive years 1932–36, inclusive. Average yearly temperatures at the 12-inch depth were uniform, ranging from 64.6° in 1931 to 68.4° in 1936.

The eggs of the 1931 series were deposited by field-collected beetles between May 4 and June 8, and these hatched in the period June 5 to July 4, 1931. During the first summer these larvae developed very slowly and by September averaged only one-fourth inch in length. As a result, none of the larvae matured in the first year. Early and throughout the spring of 1932 they consumed much greater quantities of food and by June appeared to be large enough to pupate. Later, on July 10, the first prepupa was obtained, and this specimen pupated on July 18. Pupation in the group continued throughout August, and by September 10 a total of 24, or 58 percent, of the original group of 41 had completed development, all for a 2-year cycle.[6] (Table 1.) The first transformation to adult in this series occured on August 9 and the last on October 8.

TABLE 1.—*Duration of the developmental periods of the 1931 brood of Melanotus longulus at Alhambra, Calif., 1931–34*

Life cycle (years)	Individuals	Item	Duration of period: Egg	Larval[1]	Prepupal	Pupal	Egg, larval, and pupal	Temperature[2]
	Number		*Days*	*Days*	*Days*	*Days*	*Days*	*° F.*
2	24	Maximum	33	476	14	29	531	81.0
		Minimum	26	409	1	22	459	52.0
		Average	29.0	420.1	8.2	23.7	472.8	69.1
3	5	Maximum	29	817	20	31	873	83.0
		Minimum	26	788	10	28	847	52.0
		Average	27.4	804.6	15.2	29.0	861.0	68.1
4	5	Maximum	29	1,194	16	25	1,218	87.0
		Minimum	28	1,143	8	22	1,194	52.0
		Average	28.8	1,158.8	11.2	23.3	1,218.3	68.7

[1] Includes the prepupal period.
[2] During larval period.

Of the remaining larvae in this series, 5 pupated in 1933 and 5 in 1934 for a 3- and a 4-year cycle, respectively. Of the original group only 7 succumbed. Pupation in 1933 occurred between August 22 and September 20. These pupae transformed to adults between September 22 and October 18. In this group the larval period averaged

[6] The elapsed time from hatching of the egg to the death of the adult in the spring of the second year would be slightly over 2 years

804 days and the period from egg to adult averaged 861 days. Pupation in 1934 began and terminated between August 2 and September 26, and the first and last adults were obtained on August 24 and October 21. An average of 1,158 days was recorded for the duration of the larval period, and from egg to adult an average of 1,218 days.

EFFECT OF QUANTITY OF FOOD ON RATE OF LARVAL DEVELOPMENT

In the field wireworms are constantly being subjected to a variety of unfavorable conditions any of which may adversely affect the duration of larval life. The most important of these is a deficient food supply, the lack of or an excess of soil moisture, and extremes in temperature. Graf (2) kept 7 larvae of *Limonius californicus* alive for over a year without food, and 1 individual of this series remained alive for almost 2 years. Even greater larval longevity occurred when the quantity of food given each larva was reduced from 10 kernels to only 1 kernal of wheat per month. Of a series of 10 larvae of the 1930 brood fed in this manner, 7 died between 1930 and 1936, 2 matured in 1934, and the 1 remaining larva died in August 1938, after completing 8.2 years in the larval stage. These experiments indicate that wireworms can exist and may also complete development on very small quantities of food. Since unfavorable conditions of moisture and temperature may occur at irregular intervals and as wireworms usually avert these extreme conditions by migrating to lower depths, the question of food appears to be especially significant in affecting their rate of development.

To obtain additional information on this phase, a series of larvae of the 1932 and 1933 broods of *Melanotus longulus* were divided into 3 groups with 25 larvae in each (except in group 3 of the 1932 series, which had 34 larvae) and were fed various quantities of moist wheat. Larvae of the 1932 series hatched in the period May 14 to June 13 from eggs deposited between April 12 and May 15. Those of the 1933 series hatched later, between June 2 and July 6, from eggs deposited between April 23 and June 8. All groups contained an equal number of early- and late-hatched larvae. Larvae in group 1 of each series were fed individually 10 kernels of wheat monthly between March 1 and October 1, this being the period of greatest larval activity in the field, and then 2 kernels monthly during the winter, when the larvae were least active. The larvae in groups 2 and 3 were fed 20 and 10 kernels per month, respectively, from the time of hatching.

No larvae in either brood series completed development in the first year of their existence. When the wireworm *Limonius californicus* was reared under similar conditions, an average of 4 percent matured the first year, but beetles of this species emerge and oviposit earlier than does *Melanotus longulus*, and the larvae, therefore, are subjected to a longer period of activity prior to pupation late in the summer or in the fall.

In the brood series of 1932 the first pupation occurred in the group fed 20 kernels on August 4, 1933. Pupations in all groups in 1933 terminated on September 14. In the series of 1933 the first pupa was obtained in group 1 on July 23, 1934, and the last in group 2 on September 9. A summary of the pupations in both broods and groups showed that an average of 28 percent of the larvae matured for a 2-year cycle.

In the third year (series of 1932) the first pupa was obtained in the 20-kernel group on June 10 and the last pupation occurred in this same group on August 31. Larvae completing development in the series of 1933 for a 3-year cycle began and terminated pupation in the period between August 2 and September 23. These records of early and late pupation were obtained in the 10-, 2-, and 10-kernel groups, respectively. The feeding of different quantities of wheat did not appear to have affected the rate of pupation significantly, as the percentages obtained for both broods were similar. A total of the 3-year-cycle pupation for both broods shows that 30 percent matured in the 2- and 10-kernel groups, 34 percent in the 20-kernel, and 28.8 percent in the 10-kernel group.

Larvae completing development in 4 years in the series of 1932 began and ceased pupation on August 3 and September 26, and in the series of 1933 between August 4 and September 28. Only a few pupations occurred in both broods, 4 in group 1, 2 in group 2, and 13 in group 3, or 12 percent of the total number of larvae reared.

A few larvae remained in all groups to complete development in 5 years. Of these, a total of 4 percent matured in group 1, 2 percent in group 2, and 1.7 percent in group 3. The longest larval period (1,885 days) observed during these studies occurred with the pupation, on August 2, 1937, of the remaining larva in group 1 of the brood series of 1932.

Because of the limited number of individuals that pupated in the different groups each year, it is difficult to say whether the rate of pupation was affected by the feeding of various quantities of food. A total of the pupations in the 2 broods shows that 72 percent matured in the 2- and 10-kernel groups, 68 percent in the 20-kernel group and 81.3 percent in the group fed 10 kernels of wheat continuously, indicating that 10 kernels was sufficient for accelerating the development of larvae of this species. It was observed, however, that the mortality was greater in the other groups, and had not this been the case more would have pupated and the total percentages would have equaled or exceeded that for the 10-kernel group. The main difficulty with the feeding of 20 kernels was that this large amount of food tended to favor the growth of fungi in the soil, and the excess growth undoubtedly helped to cause part of the mortality shown.

Of the 159 larvae under observation in this experiment, a total of 28 percent matured in 2 years, 31 percent in 3 years, 12 percent in 4 years, and slightly over 3 percent in 5 and in 6 years. A larval mortality of 25.8 percent occurred in both broods during the 6-year period of these studies.

EFFECT OF STERILE AND UNSTERILE FOODS ON LARVAL DEVELOPMENT

In rearing experiments started prior to 1933 the food commonly used to feed the wireworms was wheat. Wheat was used mainly because it softens readily when soaked in water, and when sprouting occurs in the cans the pressure exerted by the young shoots is not strong enough to remove the salve-can lids. When larger seeds were used, such as corn and lima beans, many of the larvae were either lost or desiccated by the drying out of the soil after the lids of the salve cans had been pushed off by the sprouting seeds. Since it was desirable to determine the effect of these foods on the rate of wireworm development, the germ of the larger seeds was killed by boiling the seeds in water for about 10 minutes, to prevent germination in the cans.

In this experiment, 25 larvae of the 1933 brood of *Melanotus longulus* were used, and each of these was fed 1 sterile lima bean monthly from time of hatching. Of unusual occurrence in this group was the fact that none of the larvae pupated in 1934, 1935, or 1936, whereas in the group of 75 of the 1933 brood, which were fed moistened wheat, 32 percent matured in 1934, 29 percent in 1935, 8 percent in 1936, and 3 percent in 1937. It was observed in these different years that the sterile-bean-fed larvae developed very slowly and were considerably smaller than those reared on wheat.

On May 1, 1936, the 17 larvae remaining in the sterile-bean series were segregated into 2 groups. Eight larvae were continued on the sterile-bean diet, while the diet of the other 9 was changed to 1 unsterilized lima bean monthly. In the latter group 3 pupations occurred between July 14 and September 1, 1936, and 6 succumbed in 1936–37. In the sterile-bean group 3 individuals died, only 1 pupated in 1938, and 4 continued as larvae to 1939 for a possible 7-year cycle. Weighings made on October 28, 1936, showed that the weight of the remaining larvae in the sterile-bean groups averaged 37 mg., and of those in the unsterile groups, 81 mg. This shows that in a period of 5 months the larvae reared on unsterilized lima beans more than doubled their weight over the more slowly developing larvae fed on sterile beans. Recently similar experiments (*9*) were conducted with *Limonius californicus* larvae and with these the same results were obtained, which appears to be conclusive evidence that wireworm development and pupation are retarded when sterile lima beans are used as food.

EFFECT OF CONSTANT TEMPERATURES ON RATE OF DEVELOPMENT

To determine the effect of higher temperatures on the rate of larval development, 2 additional series were reared in constant-temperature cabinets held at 70° and 80° F. The 30 larvae held at the lower temperature hatched in the period June 8 to July 4, 1931, from eggs deposited between May 6 and June 8. The larvae in this group were fed 10 kernels of moistened wheat monthly. The temperature at which these larvae were held averaged less than 1° higher than in the basement and, because this variation was so slight, their period of pupation occurred at approximately the same time as in the 1931-brood group reared in the basement. The number of 2-year-cycle individuals that matured, however, was greater by 15 percent than in the basement group, but there were fewer pupations in the second and third years (table 2).

TABLE 2.—*Summary of pupations and mortalities of the 1931 brood Melanotus longulus reared at constant temperatures of 70° and 80° F., Alhambra, Calif.*

Item	Pupations and larval mortalities of M. longulus			
	Reared at 70° F.		Reared at 80° F.	
	Number	*Percent*	*Number*	*Percent*
Pupations:				
1931, 1-year cycle	0	0	0	0
1932, 2-year cycle	22	73.3	22	73.3
1933, 3-year cycle	3	10.0		
1934, 4-year cycle	1	3.3		
Total	26	86.7	22	73.3
Larval mortalities:				
1931	1	3.3	4	13.3
1932	1	3.3	4	13.3
1933	2	6.7		
1934	0	0		
Total	4	13.3	8	26.6
Grand total	30	100.0	30	99.9

As shown in table 3, the average duration of the larval period for the individuals completing development in 2 years was 424 days, or only 4 days longer than the average obtained for larvae reared in the basement where the temperature extremes ranged from 52° to 81° and averaged 69.1° F. An average larval period of 779 days was obtained for the individuals maturing in 3 years, and of 1,169 days for the one individual that matured in 4 years.

TABLE 3.—*Duration of the developmental periods of the 1931 brood of Melanotus longulus, at constant temperatures of 70° and 80° F., Alhambra, Calif.*

AT A CONSTANT TEMPERATURE OF 70° F.

Life cycle (years)	Individuals	Item	Duration of period				
			Egg	Larval[1]	Prepupal	Pupal	Egg, larval, and pupal
	Number		*Days*	*Days*	*Days*	*Days*	*Days*
2	22	Maximum	33	456	20	28	515
		Minimum	26	400	2	24	452
		Average	29.0	423.7	7.7	25.5	478.3
3	3	Maximum	29	812	15	29	870
		Minimum	28	759	4	22	809
		Average	28.7	778.7	9.3	24.3	831.7
4	1		28	1,168.4	11	25	1,222

AT A CONSTANT TEMPERATURE OF 80° F.

Life cycle (years)	Individuals	Item	Egg	Larval[1]	Prepupal	Pupal	Egg, larval, and pupal
1	22	Maximum	33	447	10	19	402
		Minimum	26	276	3	16	324
		Average	30.5	331.4	5.1	17.3	370.2

[1] Includes prepupal period.

The 30 larvae reared at a constant temperature of 80° F. hatched between June 2 and 27, 1931, and were fed 10 kernels of wheat at 15-day intervals from time of hatching. As usual, no pupations occurred during the first year of existence, but in the second year 20 individuals pupated between March 15 and May 27, 1932—from 4 to 5 months prior to the time of normal pupation. One of these transformed to adult on April 1. The 2 remaining larvae pupated on August 31. With this group a total of 73 percent completed development in 1932 and 27 percent succumbed (table 2).

The shortest larval period recorded for this species occurred with the pupation of two larvae on March 15. Table 3, which gives the duration of the developmental periods, shows that the larval period of this group ranged from 276 to 447 days and averaged 331 days. At this temperature the length of the pupal period averaged 17 days, or 7 days less than the average obtained for rearings at basement temperature.

SUMMARY OF DEVELOPMENTAL STUDIES IN SALVE CANS

As shown by the summary of the rearings conducted in salve cans (table 4), there was considerable variation in the number of individuals completing development each year in the different broods.

TABLE 4.—*Numbers and percentages of Melanotus longulus, reared in salve cans, completing their development in different numbers of years during the period 1931–37*

Year series was started	Individuals completing development in—										
	2 years		3 years		4 years		5 years		6 years		Total
	Number	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*
1931	24	70.6	5	14.7	5	14.7	------	------	------	------	34
1932	21	32.8	27	42.2	13	20.3	2	3.1	1	1.6	64
1933	24	44.4	22	40.7	6	11.1	2	3.7	------	------	54
Total	69	45.4	54	35.5	24	15.8	4	2.6	1	.6	152

Also, it was observed that larvae that hatched at approximately the same time, and lived under identical conditions of food, temperature, and moisture, completed development in from 2 to 6 years. Similar variations occurred when the life cycle of the sugar-beet wireworm was studied (*8*), and Hawkins (*3*) experienced the same results when rearing larvae of *Agriotes mancus* (Say) in Maine. The greatest variation occurred in the 1931 brood, as in this group 71 percent matured for a 2-year cycle, whereas in the broods of 1932 and 1933 only 33 and 44 percent, respectively, completed development. There was but slight difference in the percentages of 3-year-cycle individuals in the broods of 1932 and 1933, but the 1931 brood had a much lower percentage than either. It appears that when food is plentiful, over 80 percent of the larvae of this species complete their development during the second and third years and a few larvae of the same series may even continue into the fourth, fifth, or sixth years before completing development.

According to the data in table 5 the average duration of the larval period is fairly consistent in the different years. Since pupation within years occurs over an average period of 54 days, considerably more variation than is shown might be expected.

TABLE 5.—*Average larval period of Melanotus longulus larvae that matured in from 2 to 6 years when reared in salve cans, Alhambra, Calif., 1931–37*

Year series started	2-year cycle		3-year cycle		4-year cycle		5-year cycle		6-year cycle	
	Records	Average larval period	Records	Average larval period	Records	Average larval period	Records	Average larval period	Records	Average larval period
	Number	*Days*	*Number*	*Days*	*Number*	*Days*	*Number*	*Days*	*Number*	*Days*
1931	24	420	5	805	5	1,159				
1932	21	451	27	795	13	1,184	2	1,565	1	1,885
1933	24	431	22	812	6	1,173	2	1,528		
Total or average	69	433	54	803	24	1,176	[illegible]	1,547	1	1,885

OUTDOOR REARING STUDIES

The tile cages used for outdoor rearings of *Melanotus longulus* larvae were set up as described under Rearing Technique (p. 6). Each cage was stocked with 25 larvae and a supply of wheat. After the second month the larvae were fed corn, because this grain sprouted more slowly, therefore was nutritive for longer periods. As this species does not produce 1-year-cycle adults, the first cage examination was delayed until October of the second year. At this time the adults were removed and the remaining larvae were returned to the cages. The same procedure was followed in the third and fourth years. Data pertaining to the rearing of the broods of *M. longulus* of 1932, 1933, and 1934 are shown in table 6.

TABLE 6.—*Summary of life-history studies of Melanotus longulus in tile cages, Alhambra, Calif., 1932–37*

Completed development for a—	1932 Brood		1933 Brood		1934 Brood		Total	
	Number	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*
2-year cycle:								
Larvae in tile cages at start	450		500		116		1,066	
Mortality, first and second years	317	70.4	270	54.0	78	67.2	665	62.4
Larvae recovered second year	6	1.3	27	5.4	33	28.4	66	6.2
Adults recovered second year	127	28.2	203	40.6	5	4.3	335	31.4
3-year cycle:								
Larvae injured by handling second year	1	.2	7	1.4	5	4.3	13	1.2
Larvae returned to cages second year	5	1.1	20	4.0	28	24.1	53	5.0
Mortality during third year	5	1.1	4	.8	3	2.6	12	1.1
Larvae recovered third year	0	0	2	.4	19	16.4	21	2.0
Adults recovered third year	0	0	14	2.8	6	5.2	20	1.9
4-year cycle:								
Larvae injured by handling third year			0	0	6	5.2	6	.6
Larvae returned to cages third year	0	0	2	.4	13	11.2	15	1.4
Mortality during fourth year			2	.4	7	6.0	9	.8
Larvae recovered fourth year			0	0	0	0	0	0
Adults recovered fourth year			0	0	6	5.2	6	.6

A summary of the outdoor rearing studies (table 6) shows that of 1,066 larvae under observation over a 6-year period, a total of 361, or 33.9 percent, matured as adults in the proportion of 47 percent of females and 53 percent of males. Nineteen, or 2.8 percent, were killed when the soil was being removed, and 686, or 64.3 percent, either succumbed or, because of being crowded, were the victims of cannibalism. Of the original 3 groups of larvae, 31.4 percent completed development in 2 years, 1.9 percent in 3 years, and only 0.6 percent in 4 years. Based on the actual number of survived larvae, these data show that 92.8 percent matured in the second year, 5.5 percent in the third year, and 1.7 percent in the fourth year.

A summary of the basement rearings in salve cans (table 4) shows that 45.4, 35.5, 15.8, 2.6, and 0.6 percent of the larvae matured in the consecutive years 1 to 6, inclusive. The more rapid acceleration in the rate of development of larvae in tile cages may be attributed, perhaps, to the higher daily temperatures that prevail out of doors during the spring and early summer months, as it is during this period, if food is available, that wireworms make their greatest growth.

The average mean soil temperatures recorded at the 4-, 8-, and 12-inch depths from the date the larvae were placed in the cages to November 1 of the second year were 74°, 70°, and 70°, averaging 71° F.; to November 1 of the third year, 68°, 69°, and 69°; and to November 1 of the fourth year the temperature recorded at each depth was 68°.

DURATION OF THE PREPUPAL PERIOD

Prior to pupation, the larvae enter the prepupal stage and, in this condition, may be identified by their inactivity, shortened bodies, and enlarged middle segments. The prepupae are enclosed in an earthen cell about three-fourths of an inch in length, formed by the larvae before they enter the prepupal state.

As shown in table 7, the first prepupa was obtained on June 5, 1934. and the last on September 21, 1935. The duration of the prepupal period varied with the temperature, ranging from an average of 7 days in 1937 to 11.4 days in 1936. The average for all years was 8.5 days.

TABLE 7.—*Duration of the prepupal period of Melanotus longulus in salve cans, Alhambra, Calif., 1932–37*

Year	Males and females			Average length of period
	Prepupal dates		Records	
	First	Last		
			Number	*Days*
1932	July 10	July 31	24	8.2
1933	July 28	Sept. 5	26	9.5
1934	June 5	Sept. 10	56	7.8
1935	July 29	Sept. 21	35	8.7
1936	July 20	Sept. 15	8	11.4
1937	July 27	Sept. 4	3	7.0
Total			152	8.5

THE PUPA

TIME OF PUPATION IN SALVE CANS

The time of pupation in salve cans was ascertained by examining the older larvae at 3-day intervals beginning about the middle of July and continuing throughout the pupation period. Larvae which then appeared to be of the prepupal type were placed on top of the soil in a depression, where they were observed at daily intervals until pupation occurred. During the 6-year period 1932–37 the earliest pupation in salve cans occurred on June 10, 1934, and the latest was on September 28, 1936. Even when the abnormal pupation in June was excluded, the longest period of pupation was 67 days in 1934 and the shortest was 42 days in 1937. With the exception of the results obtained in 1935, most of the pupations in all the years occurred in August, 65 percent taking place in that month, 25 percent in September, and 10 percent in July.

DURATION OF THE PUPAL PERIOD IN SALVE CANS

Data on the duration of the pupal period for each month of the different years are shown in figure 3. The temperatures given are an average of the daily mean basement temperatures from the date of the first pupation to that of the last adult transformation in each month.

The duration of the pupal period varied with temperature. For instance, when basement temperatures averaged 76.9° F. during August 1936 the pupal period averaged only 20.5 days, whereas during periods of low temperatures, as in September 1933, when temperatures averaged 72°, the duration of the pupal period increased to an average of 28.6 days. A summary of all records shows that during July, when temperatures averaged 76.2°, the duration of the pupal period ranged from 22 to 25 days and averaged 23.2 days. The same average was obtained in August when temperatures averaged 75.1°, but the range was greater—from 19 to 32 days. Slightly lower temperatures occurred during September (72.8°), and this was responsible for an increase in the mean to 26.5 days and in the range from 22 to 32 days. Over the 5-year period 1932–36 the pupal period averaged 24.4 days.

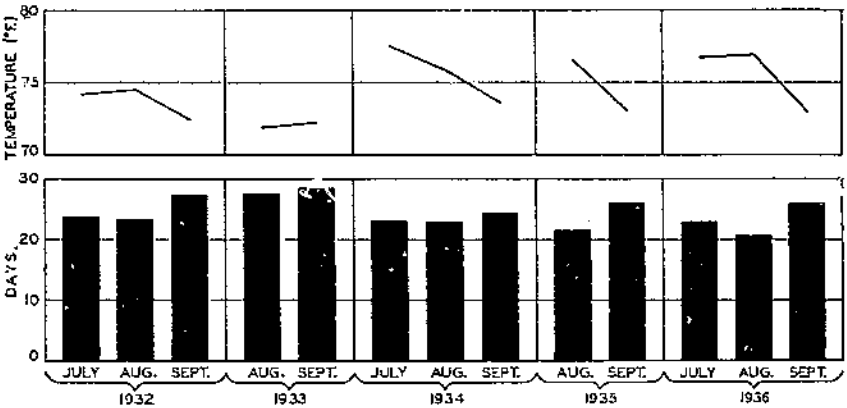

FIGURE 3.—Duration of the pupal period of *Melanotus longulus*, as compared with mean basement temperatures at Alhambra, Calif., 1932–36.

EFFECT OF SOIL CONDITIONS, HANDLING, AND CULTURAL OPERATIONS ON SURVIVAL OF PUPAE

Although pupae and prepupae are extremely delicate, they are not so susceptible to adverse conditions as would be supposed. The larvae experience no difficulty in pupating in extremely dry soils, as on several occasions pupation and emergence of the adult were observed in salve cans containing soil unchanged for over 2 months and dry to the point of being powdery. Some mortality resulted when the soil was overly wet, but this was due to the increased growth of fungus in the salve cans. It is doubtful whether any appreciable mortality would result in the field from this condition, as there the pupae would be confined in their pupal cells, in a more protected state. On one or more occasions practically all pupae or prepupae reared in salve cans were dumped vigorously into a screen, from which they were picked up with tweezers and placed in a depression on the soil surface. The mortality from such treatment was negligible. Considerable mortality of pupae may result from plowing, either through injury or exposure. Shirck (*6*), in experiments conducted in Idaho, found that plowing to a depth of 8 or 9 inches during the first week of August killed approximately 75 percent of the pupae of *Limonius*.

Dead or injured pupae and prepupae were occasionally found to be heavily infested with mites,[7] but these apparently were only scavengers and not of the parasitic type.

DEPTH OF PUPATION

The depth of pupation was determined by confining 20 large or mature larvae in each of 6 tile cages (6 by 24 inches) containing sandy loam soil, early in June. Corn was added at the time of their confinement and at 6-week intervals thereafter. The soil within the cages was kept as near optimum condition as possible by occasional irrigations. The cages were taken up late in September, and each 4 inches of soil was removed separately and sifted to ascertain the depths of the various stages. At the time of examination adults as well as pupae were found and, as these adults were recovered in their pupal cells, the records pertaining to their depth in the soil were included with those of the pupae. Apparently most of the larvae had died or had succumbed to cannibalism, because of the 120 larvae confined in the cages only 48 completed development and only 4 remained. That this insect pupates over a rather wide range of depths was indicated by the following results: 21 percent of the pupae were recovered between the 6- and 8-inch depths, 29 percent between 9 and 12 inches, 23 percent between 13 and 16 inches, 8 percent between 17 and 20 inches, and 19 percent between 21 and 24 inches.

THE ADULT

EMERGENCE IN THE FIELD AND FROM TILE CAGES

The adults of *Melanotus longulus* are unlike most elaterids in that they very rarely appear on the surface on bright sunny days. Emergence in tile cages occurred after the sun had become less intense, usually after 4 p. m., whereas on cloudy days they were recovered throughout the day, starting about 11 a. m. A few adults were

[7] According to H. E. Ewing, these mites are migratory nymphs of some species of Tyroglyphidae, probably not parasitic.

collected in the field on alfalfa late in the morning, but the larger collections were made late in the afternoon. Emerged adults that remained overnight in tile cages were found under small clods or sticks on the following morning, and these, especially the males, would delay resumption of activity until late in the afternoon.

Data on outdoor emergence were obtained by using unglazed tile cages as described previously (*7*). Early in the summer 25 large mature larvae and a small quantity of corn were buried in each cage between the 6- and 12-inch depths. Larvae confined in this manner had sufficient time to feed and to orient themselves prior to entering the prepupal stage. The cages were irrigated at intervals during the summer and fall and, prior to beetle emergence, were fitted with 18-mesh, cylindrical, removable screen tops. During emergence the beetles were removed daily, usually about 5 p. m.

In 1931 emergence of *Melanotus longulus* adults from tile cages began on April 14. Soil temperatures on April 8 and 9 reached a maximum of 92° F. at the 4-inch depth, dropped to 82° on April 10, and to 77° on April 14, the day of initial emergence. The higher temperatures earlier in the week apparently supplied the stimulus for the appearance of the beetles on April 14. During the first 3 weeks the rate of emergence increased gradually but was retarded in the fourth week, ended May 10 by low temperatures in the previous week. The peak of emergence took place during the week ended May 17 and the largest daily emergence was recorded on May 11. Emergence in 1931 extended over a period of 49 days and terminated on June 1 (fig. 4).

In the field adults were taken on April 30 near Temple, Los Angeles County, Calif., by sweeping alfalfa. A few were collected in this same locality on May 9 but none on May 26 or 28.

Records of adult emergence from tile cages were not available for either 1932 or 1933. Near Ventura in 1932 a single adult was collected on March 19 under a malva trap [8] used in trapping adults of *Limonius californicus*. A few were taken in these traps each day thereafter until the end of the month. Beginning on April 6, and continuing to April 20, large numbers of both males and females were trapped. In Orange County the first adults were collected under malva traps near Smelzer on April 14, on alfalfa in the vicinity of El Monte, Los Angeles County, on April 16, and in larger numbers near Temple, Los Angeles County, on May 15.

In 1933 malva traps were set out in an infested beanfield at a locality in Ventura County for the purpose of trapping *Limonius californicus* adults (*1*). These same traps were used for emergence studies of *Melanotus longulus*. Table 8 presents a summary of these data, based on the daily collection of the adults during the entire emergence period.

As determined from malva-trap records, beetle emergence in 1933 started on April 6, reached a seasonal peak during the week ended April 26, and terminated after a period of 42 days, or during the week ended May 17.

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[8] Traps consisted of loose piles of *Malva parviflora* L., 3 feet in diameter, placed 100 feet apart in shallow excavations.

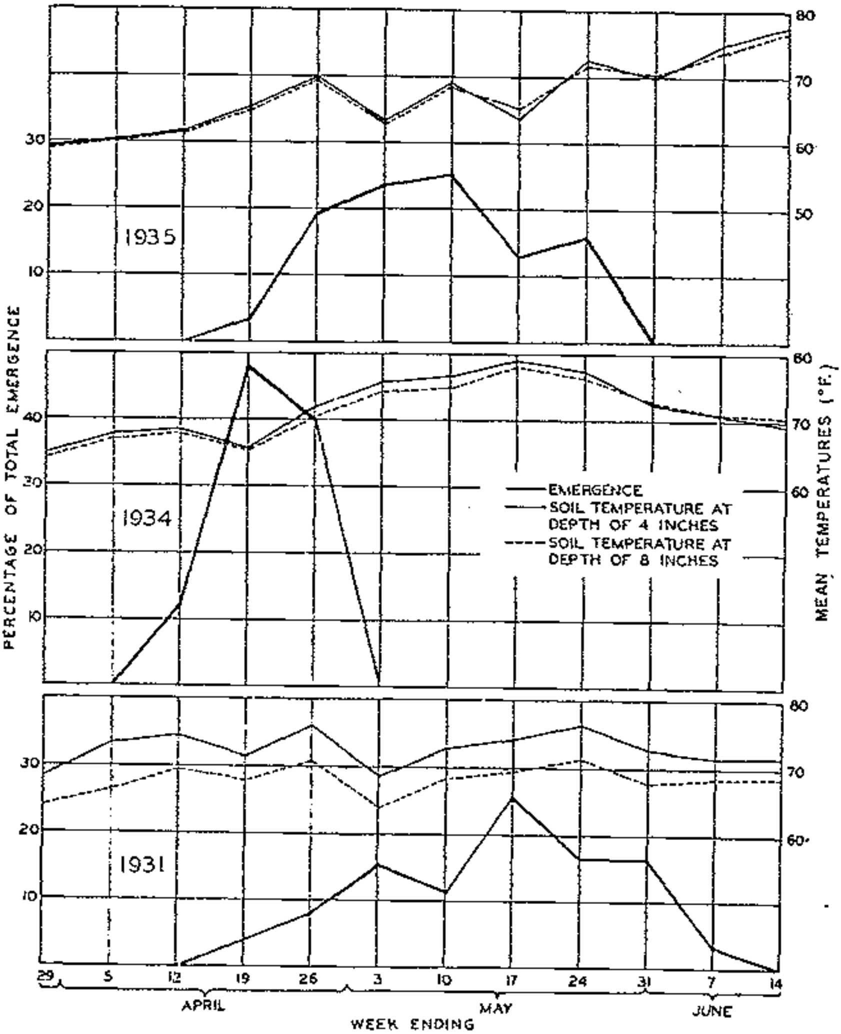

FIGURE. 4.—Time and rate of emergence from tile cages of adults of *Melanotus longulus*, Alhambra, Calif., 1931, 1934, and 1935.

TABLE 8.—*Melanotus longulus adults collected weekly from malva traps, Ventura, Calif., 1933*

Date (1933)	Adults collected		Date (1933)	Adults collected	
	Number	*Percent*		*Number*	*Percent*
Apr. 6-12	11	2.6	May 4-10	29	7.0
Apr. 13-19	69	16.6	May 11-17	4	1.0
Apr. 20-26	256	61.7			
Apr. 27-May 3	46	11.1	Total	415	100.0

At Alhambra one male was taken in a tile cage on April 5 and a male and female were taken on May 12 and 20, respectively.

In 1934 emergence records were again obtained from tile cages and in that year they were based on a total of 25 beetles, which emerged over a period of 20 days between April 6 and 25. As shown in figure 4, the peak of emergence occurred from 2 to 3 weeks earlier than in 1931 or 1935. This may have been due to higher soil temperatures earlier in the season, which accelerated the movement of the adults in the soil. Females appeared on April 18, approximately 2 weeks after the beginning of male emergence. The sex ratio of the adults that emerged was 52 percent males to 48 percent females. Near Ventura adults appeared slightly earlier, as they were taken under malva traps on March 29. Females collected and dissected on April 14 were observed to be heavily laden with eggs.

In 1935 adult-emergence records from tile cages were more complete, being based on a total of 203 beetles, which emerged over a period of 36 days between April 18 and May 23. In the week prior to emergence, soil temperatures at the 4-inch depth reached a maximum of 70° on several occasions and 75° F. on the day preceding emergence. On the day of initial emergence, the maximum was 79° and on the day following, 81°. Apparently this sudden rise in temperature provided the impetus for the first appearance of the beetles on April 18. During the first week of emergence males only were in evidence and they also outnumbered the females during the second and third weeks; however, females were more numerous in the fourth and fifth weeks. As shown in figure 4, there was a decided drop in soil temperatures during the week ended May 3, but this did not appear to have affected the rate of emergence. In all other weeks the rate of emergence increased or decreased according to corresponding changes in temperature. As to sex, the issuing beetles were in the ratio of 60.1 percent males to 39.9 percent females.

Records for 1936 show that only five adults emerged from a group of tile cages containing a series of 1934-brood *Melanotus longulus*. These were all males, and they emerged in the 5-day period April 17 to 21.

SEX RATIO

The data on sex ratio of the adults collected, based on the dissection of 494 beetles reared in salve cans and tile cages in the period 1931–37 (table 9), show that there was a gradual increase in the percentage of females as the length of the life cycle was increased. Over the entire period of development, however, the proportion of males and females reared in salve cans was about equal, whereas in the tile cages males were slightly in excess.

TABLE 9.—*Proportion of sexes of Melanotus longulus of different maturing age, reared in salve cans and tile cages, Alhambra, Calif., 1931–37*

Period in larval stage (years)	Reared in salve cans		Reared in tile cages	
	Total	Females	Total	Females
	Number	*Percent*	*Number*	*Percent*
2	55	38.2	335	42.1
3	51	56.9	20	60.0
4	22	50.0	6	66.7
5	4	75.0	------	------
6	1	100.0	------	------
Total	133	48.9	361	43.5

MATING

Mating usually takes place late in the afternoon on the day of emergence. More matings were observed on cool, cloudy days than on bright, sunny days or when higher temperatures prevailed. One mating appears to be sufficient, as females mated but once have deposited the normal number of fertile eggs.

PREOVIPOSITION PERIOD

The duration of the preoviposition period for females confined in the basement and in outdoor cages is shown in table 10. The average for 26 females was 10.7 days, with a maximum of 29 days in 1933 and a minimum of 2 days in 1931. It is noted that considerable variation exists in the averages obtained in the basement in 1931 and 1933. This was due, as was the case with *Limonius californicus*, to the difference in time of matings in these years. In 1931, when the low average was recorded, the females emerged and mated in the period April 15 to June 4, and in 1933 on April 14 and 15. In 1931 several of the late-emerged females began egg deposition in from 2 to 3 days, which accounted for the low average shown. There was also considerable variation outdoors in 1934 and 1935, but this was probably due to the difference in temperature and to the limited number of individuals under observation.

TABLE 10.—*Preoviposition period of adults of Melanotus longulus reared in salve cans and tile cages and later confined either in the basement or in outdoor oviposition cages, Alhambra, Calif., 1931–35*

Year	Confined during oviposition period in—	Total records	Average preoviposition period	Average mean basement or soil temperature
REARED IN TILE CAGES OUTDOORS				
		Number	*Days*	*°F.*
1931	Basement	9	4.1	65.6
1934	Outdoor cages	6	9.5	[1] 67.5
1935	do	6	17.3	[1] 67.2
REARED IN SALVE CANS IN BASEMENT				
1933	Basement	5	16.2	64.8
Grand total or average		26	10.7	66.3

[1] Temperatures at 4-inch depth in soil.

OVIPOSITION

In obtaining oviposition records, females reared in tile cages were mated on the day of their emergence. When adults reared in salve cans were used they were removed and mated at the time of first female emergence in outdoor cages or in the field. Pairs obtained were confined and allowed to oviposit either in 1-ounce salve cans in the basement or in specially constructed outdoor oviposition cages filled with 60-mesh soil with a moisture content ranging from 12 to 16 percent (dry weight). Each day thereafter until eggs were found, the soil was removed, washed through a 60-mesh sieve, and fresh soil was added. After oviposition began the soil was washed and the eggs were recovered at weekly intervals. An earlier paper (7) gives additional information and methods of constructing oviposition cages. Table 11 presents a summary of the oviposition records of 26 females during the years 1931 to 1935, inclusive.

TABLE 11.—*Duration of the oviposition period, also fecundity and percentages of eggs deposited at weekly intervals in the basement and in outdoor cages by salve-can- and tile-reared Melanotus longulus adults, Alhambra, Calif., 1931–35*

Type of rearing cage	Location of oviposition cages	Year	Average mean temperature	Females	Average eggs deposited per female	Average length of oviposition period	Eggs laid during indicated week of oviposition period						
							First	Second	Third	Fourth	Fifth	Sixth	Seventh
			°F.	Number	Number	Days	Percent	Percent	Percent	Percent	Percent	Percent	Percent
Tile	Basement	1931	[1] 67	9	134	17	55	31	13	1	----	----	----
Salve cans	do	1933	[1] 66	5	302	40	46	9	17	7	15	5	1
Tile	Outdoors	1934	[2] 73	6	192	24	12	45	22	17	4	----	----
Do	do	1935	[2] 69	6	166	14	61	36	3	----	----	----	----
Total or average [3]			69	26	173	22	42	28	15	7	6	2	0.0

[1] From date of mating to termination of oviposition.
[2] Average mean soil temperature at 4-inch depth.
[3] The averages are weighted.

In 1931 oviposition indoors was based on the egg-laying activities of 9 females which emerged from tile cages and were mated in the period April 15 to June 4. Despite low maximum basement temperatures, which ranged from 61° to 68° F., 1 female began ovipositing on April 19, less than 4 days after mating. Oviposition by this group continued over a period of 70 days until June 27. The extent of oviposition of this species in the different weeks is closely related to the records obtained for *Limonius californicus*. As shown in table 11, more than half the total number of eggs were laid during the first week, with diminishing numbers in the second, third, and fourth weeks. Individual egg totals ranged from 75 to 185, averaging 134 eggs. Basement temperatures were fairly uniform throughout the entire egg-laying period. No oviposition records were obtained in 1932.

In 1933 complete oviposition records were obtained for five salve-can-reared females confined in the basement. In this group, which mated on April 14 and 15, two females deposited eggs 9 days later, on April 23. Oviposition continued over a period of 58 days, until June 19.

One female in this group had the longest preoviposition period recorded during these studies. Mated on April 15, she deposited her first eggs 29 days later, on May 14. This female also deposited the largest number of eggs, a total of 473. Maximum temperatures in the basement during the activities of these females ranged from 59° to 78° F., the average (66.3°) being similar to that recorded in the studies of 1931.

As is usually the case, the greatest number of eggs was laid during the first week, a decline was noted in the second, and slight increases in the third and fifth weeks. One female reversed the procedure of egg deposition in that most of the eggs were laid during the fifth week. It was observed that total egg deposition per female greatly surpassed the individual records obtained in 1931, and this may have been due to the fact that these females were larger, having originated from older and considerably larger larvae than those used in the earlier studies.

Pairs used in outdoor oviposition studies in 1934 were confined in metal cages having plaster-of-paris bottoms and filled with 60-mesh soil. These were imbedded about 2½ inches deep in moist soil in a sunny exposure. Owing to the lack of recording instruments, temperatures at the bottom depth of the cages were not obtained in either 1934 or 1935, hence the mean temperatures ordinarily recorded at the 4-inch depth in the sun have been included. Naturally these temperatures would average slightly lower than prevailing temperatures nearer the surface. This group of 6 females began ovipositing on April 15 and continued to do so over a period of 46 days, until May 29. The average egg deposition was lowered somewhat because 1 female died prematurely and, when dissected, was found to contain 228 eggs. Contrary to results obtained in previous years in the basement, the adults in this group, because of their earlier emergence and the possibility that their eggs were not fully developed, deposited most of their eggs in the second week, with the numbers gradually decreasing in the third, fourth, and fifth weeks.

Oviposition studies in 1935 were again conducted out of doors in cages located in a sunny exposure. The records were based on six females which emerged from the tile cages and mated between April 26 and May 9. Egg deposition in this group began on May 11 and terminated 32 days later, on June 11. This was the shortest oviposition period recorded during these studies.

In combining all salve-can-oviposition data (table 11), it is noted that the greater number of eggs were laid during the first week after oviposition began, and this was also true out of doors in 1935. An exception to this occurred out of doors in 1934, when most of the eggs were laid during the second week. The percentage totals of the first and second week in each location, however, show a close similarity in the rate of egg deposition. In salve cans over 68 percent of the eggs were deposited in this period, and in outdoor cages 71 percent. About 15 percent of the eggs were laid during the third week in each location, and from that time the percentages decreased. Oviposition out of doors terminated during the fifth week and in the basement during the seventh week.

During the 4-year period in which oviposition studies were conducted, both in salve cans and in outdoor cages, the average number of eggs deposited per female was 173, the maximum 473, and the minimum 31. The salve-can-reared females, being larger because of being subjected to an excess of food as larvae, deposited more eggs on an average than did the smaller, tile-reared adults. One female from the salve-can group deposited the maximum of 473 eggs. Fewer eggs were deposited out of doors because of the higher temperatures which prevailed, causing some of the beetles to die prematurely. Altogether a total of 566 eggs was obtained by dissection; and if these were included with the total number of eggs deposited, the average rate of egg deposition would be increased to 195.

The duration of the oviposition period varied according to the manner of rearing the females and to their location during egg deposition. Females reared in salve cans and confined in the basement, where low temperatures prevailed, oviposited over a considerably longer period than the females reared in tile cages and confined in outdoor oviposition cages. Temperatures were higher out of doors, and this would naturally tend to shorten the longevity period of these females. They undoubtedly also would be affected by the high soil temperatures which they would encounter in their movement surfaceward prior to emergence in outdoor cages. The records show a maximum oviposition period of 49 days in 1933, a minimum of 6 days in 1931, and an average of 22 days for the 26 females under observation.

LONGEVITY OF ADULTS

Data pertaining to the longevity of *Melanotus longulus*, as shown in table 12, concern only the life of the adults from time of mating until their death in salve cans or in outdoor cages, which were used for obtaining records of oviposition. The life of the adult in the soil may range from 7 to 8 months, depending on the time of adult transformation in the fall and emergence in the spring. No food was provided the adults in their respective containers, since this species has never been observed to feed.

Records of male longevity in 1931 were misplaced, hence only the duration of female life is shown. Although the mean temperatures of 1931 and 1933 in the basement were similar, the longevity of salve-can-reared females averaged nearly 25 days longer in 1933 than for the same sex reared in tile cages in 1931. The maximum duration of life was also longer by 11 days, and the minimum by 26 days. These

TABLE 12.—*Longevity of adults of Melanotus longulus from mating to death, when reared under different conditions, Alhambra, Calif., 1931–35*

Year	Males				Females			
	Records	Longevity			Records	Longevity		
		Average	Maximum	Minimum		Average	Maximum	Minimum
	Number	*Days*	*Days*	*Days*	*Number*	*Days*	*Days*	*Days*
REARED IN TILE CAGES IN BASEMENT								
1931					9	37.3	55	21
REARED IN SALVE CANS IN BASEMENT								
1933	5	41.0	63	23	5	61.6	66	47
Total or average	5	41.0	63	23	14	46.0	66	21
REARED OUTDOORS IN TILE CAGES								
1934	6	22.3	35	9	6	38.3	40	30
1935	6	22.7	35	13	6	34.8	42	28
Total or average	12	22.5	35	9	12	36.6	49	28
Total or average, 1931-35, inclusive	17	27.9	63	9	26	41.0	66	21

extreme differences in longevity may be attributed to the variation in temperatures in the two locations in which the adults were confined during their dormant period.

The longevity of salve-can-reared males in 1933 ranged from 23 to 63 days, averaging 41 days. For males reared in tile cages and confined in outdoor oviposition cages, the average duration of life was 22.3 days in 1934 and 22.7 days in 1935. Tile-reared females remained alive over an average period of 38.3 days in 1934 and 34.8 days in 1935. The longest record of female longevity out of doors was 49 days and for a male 35 days.

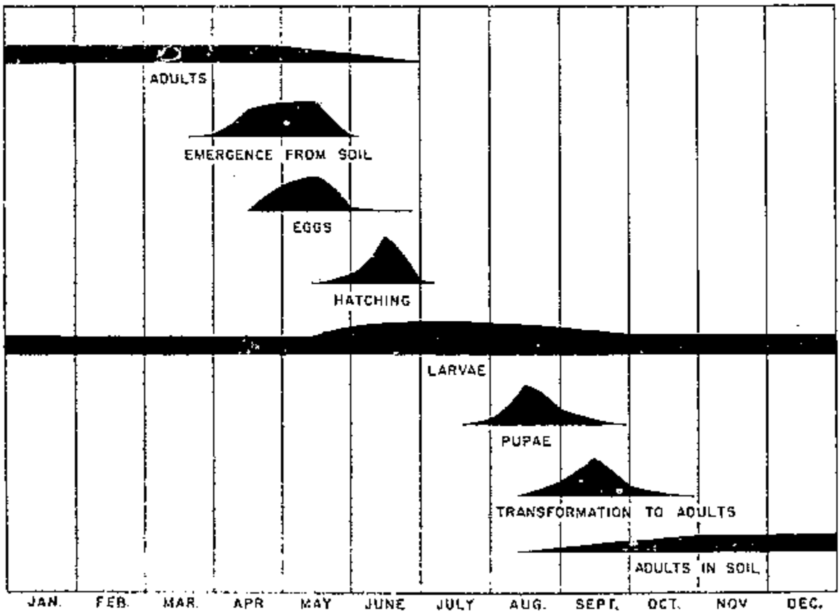

FIGURE 5.—Seasonal history of *Melanotus longulus*, in southern California during the period 1931 to 1937

SEASONAL HISTORY

The seasonal history of *Melanotus longulus* (fig. 5) was based on field and laboratory studies at Alhambra and on the data obtained from malva traps in Ventura County. The seasonal history varied considerably from year to year, depending on precipitation, temperature, soil types, drainage, and the kind of crops grown in the different localities. In 1932 adults were collected in Ventura County as early as March 19, whereas in 1935 in Alhambra adults did not emerge from cages until April 18. In other years emergence in cages occurred during the first 2 weeks of April. The peak of emergence in most years took place between April 13 and 26 and terminated by the end of May. Adults mate immediately upon issuing from the soil. Dissemination of this species is mainly by flight. Both males and females, even though the latter may be heavily laden with eggs, are strong, vigorous fliers. They are especially active on cloudy days or late in the afternoon on bright sunny days. During periods

CORRECTION

Technical Bulletin No. 858, Life History of the Wireworm *Melanotus longulus* (Lec.) in Southern California.

On page 27, in the paragraph under the heading "Summary," the first line of the paragraph should read as follows:

The wireworm *Melanotus longulus* ranks next to *Limonius cali-*

of strong winds adults cease flying and crawl to the base of plants or under clods and debris for protection.

Egg deposition began as early as 2 days and as late as 29 days after emergence. The average preoviposition period was 11 days. In laboratory cages first eggs were obtained on April 15, 1934, and the latest date that eggs were obtained was June 27, 1931. Of the 4,505 eggs under observation, 42 percent were deposited during the first week after oviposition began, 28 percent during the second week, 15 percent in the third week, 7 percent in the fourth week, 6 percent in the fifth, and 2.3 percent in the sixth and seventh weeks.

The first larvae were obtained on May 13, May 15, and June 2 in the years 1932, 1934, and 1933, respectively. The latest hatching date was July 6, 1933. Although larvae were reared under identical conditions of food, temperature, and moisture, their rate of development in the different years varied considerably. Of a total of 200 larvae reared in salve cans on various quantities of wheat, 76 percent matured and 24 percent succumbed. Of the surviving larvae, 45 percent matured in 2 years, 35 percent in 3 years, 16 percent in 4 years, 2.6 percent in 5 years, and 0.7 percent in 6 years. None completed development the first year in either salve cans or tile cages.

A total of 1,066 larvae were reared in tile cages, and of these 686, or 64.3 percent, succumbed or were the victims of cannibalism. Of the larvae that matured, 92.8 percent completed development in 2 years, 5.5 percent in 3 years, and 1.7 percent in 4 years. The more rapid acceleration in development of these individuals was attributed mainly to the higher temperatures prevailing out of doors during the early part of the spring and summer.

The first pupation in salve cans occurred on July 18, 1932, and the latest record was on September 28, 1936. Ten percent of the larvae pupated in July, 65 percent in August, and 25 percent in September.

The first adult transformed on August 12 and the last on October 28. The adults remain in the soil in the pupal cells during the fall and winter and emerge in the spring.

NATURAL CONTROL

Except for the carabids *Calosoma cancellatum* Esch. and *C. semilaeve* Lec., which have been found feeding on the adult, and birds—as listed by Graf (*2, pp. 46–47*)—which also destroy larvae, pupae, and adults of *Limonius californicus* during plowing operations, no other important enemies of *Melanotus longulus* have been observed.

SUMMARY

Except for the carabids *Calosoma cancellatum* Esch. and *C. semifornicus* in importance as a pest of vegetable and grain crops in southern California. The larvae not only destroy germinating seeds but also burrow into and kill growing plants and damage potato and root crops. Lima bean growers whose fields are infested plant an additional 40 to 50 pounds of seed per acre, and even then there are times when replanting is necessary in order that a satisfactory stand may be obtained. This wireworm and the species *L. californicus* may also be responsible for the "thinned-out" condition observed in sugar beet, tomato, corn, lettuce, and alfalfa fields. Based on counts made in lima bean rows, the larvae of *M. longulus* comprise about one-fourth of the wireworm population in beanfields.

Dissemination is mainly by flight, both male and female beetles being strong, vigorous fliers, especially active on cool, cloudy days.

In moist soil, as shown in data obtained by confining beetles outdoors in oviposition cages, females deposit over 70 percent of their eggs in the first inch, 18 percent in the second inch, 7 percent in the third, and 3 percent in the fourth.

Judging by experiments conducted in salve cans, the duration of the incubation period was found to vary according to the changes in temperature in the different months and years. Individual records of incubations were from 25 to 45 days, averaging 31 days. The shortest monthly average was 25.5 days for eggs deposited during April and May 1934, when temperatures averaged 72.5° F., and the longest monthly average recorded was 39.5 days for eggs deposited during April 1933 at an average temperature of 66°.

Of three broods of larvae, reared in salve cans in 1931–33, hatched between May 13 and July 6, and fed various quantities of wheat monthly, 45.4 percent matured in the second year, 35.5 percent in the third, 15.8 percent in the fourth, 2.6 percent in the fifth, and 0.6 percent in the sixth year. Because of the slow rate of development of these larvae during the first summer, none under observation had completed development in the first year. The average duration of the larval period was 433 days for the 2-year-cycle individuals, 803 days for the 3-year cycle, 1,176 days for the 4-year cycle, 1,547 days for the 5-year cycle, and 1,885 days for the one individual completing development in 6 years.

Of a total of 1,066 larvae of the broods of 1932, 1933, and 1934, reared in outdoor cages, only 34 percent matured as adults. A few were killed when the soil was being removed for examination, but the greater number either succumbed or were the victims of cannibalism. Higher soil temperatures outdoors in the early spring and summer accelerated larval development, as these rearings, based on the total number of adults recovered, show that 92.8 percent matured in the second year, 5.5 percent in the third, and 1.7 percent in the fourth year.

Larval development was accelerated and pupations occurred prematurely when larvae of this species were confined in salve cans at a constant temperature of 80° F. At 70° larval development and pupations were in accord with the rearings conducted at basement temperature. Larvae fed on sterile lima beans in salve cans developed much more slowly than those fed on fertile moistened wheat. The group fed on sterile lima beans, with the exception of one pupa in 1938, failed to complete development over an elapsed period of 7 years.

Judging by records of individuals confined in salve cans, the duration of the prepupal period was found to range, according to the changes in temperature, from an average of 7 days in 1937 to 11.4 days in 1936, and the average for all years was 8.5 days. The earliest pupation in salve cans occurred on June 10, 1934, and the latest was on September 28, 1936. The longest period of pupation was 68 days in 1934, and the shortest was 42 days in 1937. Over a period of 6 years, the average period of pupation was 54 days. A summary of all pupations showed that 10 percent of the larvae pupate in July, 65 percent in August, and 25 percent in September. The duration of the pupal period ranged from 19 to 32 days and averaged 24.3 days. In tile cages pupae were recovered between the 6- and 24-inch depths but the greater number between the 9- and 12-inch depths.

Adult emergence in the field, as determined by collections made in malva traps and by sweeping alfalfa, occurred as early as March 19 in Ventura County and in laboratory cages on April 6. The time of peak emergence in cages varied with the temperature in the different years, and occurred within the period April 13 to May 17. The latest date of adult emergence was June 1.

The duration of the preoviposition period in cages for females reared in salve cans and in outdoor cages ranged from 2 to 29 days, averaging 10.7 days.

Females confined in cages out of doors began egg deposition on April 15 and those in salve cans began on April 19. Oviposition terminated in salve cans on June 27 and in outdoor cages on June 7. The peak of oviposition occurred in the second and third weeks of May. Females confined in salve-can cages in the basement deposited eggs at the rate of 50, 19, 15, 4, 9, 3, and 0.4 percent in the consecutive weeks 1 to 7 after oviposition began, whereas in outdoor cages the percentages were 30, 42, 15, 11, and 2 in weeks 1 to 5, inclusive.

The minimum fecundity for females confined and reared in outdoor cages was 31 eggs, the maximum was 303, and the average was 149. For the larger females reared and confined in salve cans, the number of eggs deposited ranged from 117 to 473, averaging 194. The average fecundity of all females under observation was 173 eggs.

In the basement, where lower temperatures prevailed, the duration of the oviposition period in salve cans was lengthened to an average of 40 days, whereas in outdoor cages at higher temperatures the period was much shorter, averaging only 18 days. For all females the oviposition period ranged from 6 to 49 days, averaging 22 days.

Males reared in cages outdoors remained alive for 22 days after emergence, and females for 37 days. Lower temperatures prevailed in the basement and, as a result, the longevity of males was increased to an average of 41 days and that of the females to 46 days. The maximum longevity record for males was 63 days and for females 66 days.

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