BULLETIN 304 MARCH, 1929

Connecticut Agricultural Experiment Station

New Haven, Connecticut

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The Asiatic Beetle in Connecticut*

ROGER B. FRIEND

INTRODUCTION

The Asiatic beetle, *Anomala orientalis* Waterhouse, presumably imported into Connecticut directly from Japan, is a serious pest of lawns in New Haven. It has not become abundant over any great area in the United States as yet, and its status as an enemy to agriculture is not known, although it has injured sugar-cane in Hawaii. However, there is no question as to the damage the larvae can do to lawns in a residential district. Over $30,000 has been spent from State and Federal funds in a territory about one mile square, and the inhabitants of that territory have probably spent at least an equal sum in an effort to prevent the spread of the insect from the infested area to other parts of the State.

This bulletin includes the results of the investigations carried out by the writer at New Haven, Connecticut, on the biology and control of the Asiatic beetle during the years 1926, 1927, and 1928. In view of the fact that this is an introduced species which seems to have become well established, a brief discussion is given of the climatic and soil conditions of the infested region. It is hoped that the pages given over to the description of the various stages will aid in determining the species, for the adults vary in color, and the immature stages superficially resemble other Scarabaeidae. The observations on the life history and habits cover three seasons, but most of the control work described in this bulletin was carreid out in 1928.

From the first, this work was planned as a co-operative project between the Federal Bureau of Entomology and this Station, and Mr. Loren B. Smith, of the Japanese Beetle laboratory has made many helpful suggestions during the progress of the investigations. Messrs. Fleming, Fox, Lipp, Hallock, King, and Smith of the Bureau have reviewed the manuscript of this bulletin and made some helpful criticisms, for which the writer expresses his appreciation.

The writer was assisted in the work during 1926 by Mr. Paul A. Davis, in 1927 by Mr. George R. Biecher, and in 1928 by Mr. Benj. W. McFarland.

Assistance has also been given the writer at various times by members of the staff of the Experiment Station, particularly

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*The Japanese Beetle Laboratory of the Bureau of Entomology, U. S. D. A., has collaborated with the Connecticut Agricultural Experiment Station in planning and carrying out these investigations.

Messrs. Fisher, Walden, Johnson, Morgan, and Jacobson. A number of citizens of Westville, New Haven, have permitted their lawns to be used for experimental purposes, not always to the benefit of the property, and the general co-operation by the inhabitants of this part of New Haven has been excellent. The entire Asiatic beetle project has been under the direction of the Station Entomologist, Dr. W. E. Britton. To all these, the writer expresses his thanks.

HISTORY AND DISTRIBUTION

Anomala orientalis was first described by Waterhouse in 1875 from specimens taken in Japan and the habitat given as Kawachi, Nagasaki, and Hakodadi. In 1895, Lewis revised the Lamellicornia of Japan and stated that the beetle occurred on all the islands. Some time before 1908, according to Muir, it was imported into Hawaii and became established in the cane fields on the island of Oahu. In 1920 adults were collected in a nursery in New Haven, Connecticut, and in 1922 complaint was received of severe injury to lawns by the larvae. In view of the fact that this nursery imported plants, some of them with earth about the roots, from Japan in 1911, 1912, and 1916, it is probable that the insect came directly from Japan on imported nursery stock. There were two small infestations of beetles in West Haven, one of which has been eradicated, a few miles from the New Haven infestation, but except for this there are now no known infested areas in Connecticut outside of New Haven. The West Haven infestations were probably started by beetles accidentally brought from New Haven. In 1926, the beetle was discovered in Jericho, Long Island, New York, and it has since been found in large numbers there and in neighboring towns. Whether the beetles on Long Island came directly from Japan or are the result of a spread from New Haven is not known, and there is, of course, the remote possibility that the beetles spread from Long Island to New Haven. Since 1925 a few beetles have been found in several towns in Westchester County, New York, and Elizabeth, New Jersey and larvae have been found in Rutherford, New Jersey. The known distribution of *Anomala orientalis* includes the islands of Japan; Oahu Island in the Territory of Hawaii; New Haven and West Haven, Connecticut; Long Island and Westchester County, New York; Elizabeth and Rutherford, New Jersey. In the United States the larvae occur in the turf of lawns and similar places, and have not yet been found to injure agricultural crops. At Rutherford, N. J., at several localities in Westchester County, and on Long Island, New York, and at New Haven, Connecticut, this insect is present in sufficiently large numbers to be considered a serious pest. There is a possibility that it may become injurious to grain and forage crops some time in the future unless its increase and spread are checked.

Aside from the evidence furnished by the dates of importation of nursery stock from Japan, the great abundance of larvae found in lawns in New Haven, where instances of 1000 grubs per square yard of turf are not rare, indicates that this insect was present several years prior to its discovery in 1920. The rate of reproduction is not high when compared with that of other insects, nor is the natural spread very rapid. In Hawaii, where there are at least two generations a year and perhaps three, the known distribution in 1918, at least ten years after introduction, extended over an area of but six square miles. There is but one generation a year in New Haven and when one considers the habits of the insect and the tendency to concentrate in small areas, it is not remarkable that the present known infested area here should cover only about one square mile (Fig. 33). The adults do not fly far nor much of the time, and they are difficult to discover. In 1926, twelve scouts secured 2402 adults in two months, which is a small number compared with the number of larvae present in any one infested lawn. The larvae are easily confused with

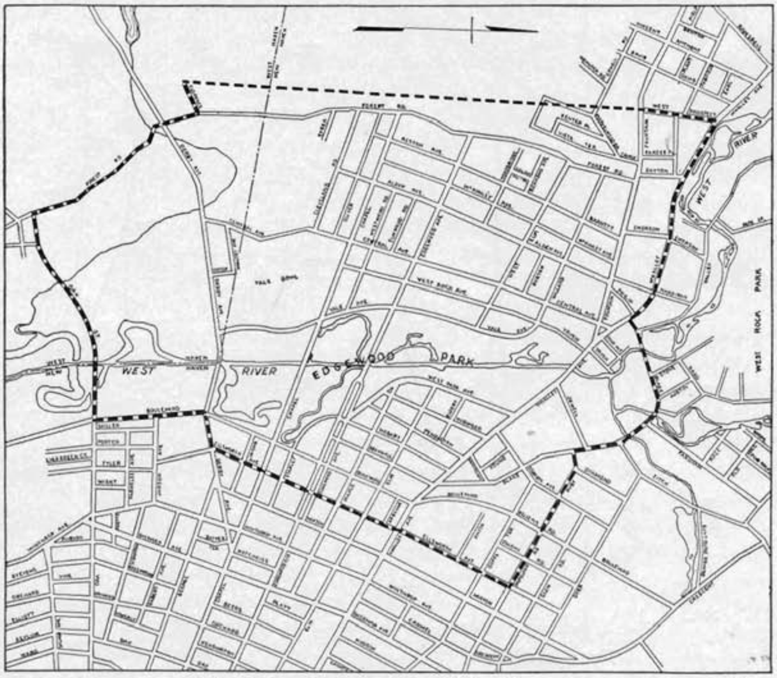

FIG. 33. Map of the Westville section of the City of New Haven. The area enclosed by the heavy dotted line is now quarantined on account of the Asiatic Beetle.

those of other Scarabaeidae, and no injury to grass is apparent when the infestation is below about 150 larvae per square yard. It is quite possible that this insect occurs in localities where it is at present unknown. There was no quarantine in force in Connecticut until 1926, and the Japanese beetle quarantine, which would affect the distribution of Anomala larvae, was not extended to include the Long Island infestation until the same year. Up to this time plants with soil about the roots could have been freely shipped to any part of the country from the infested territory, and the larvae could have become distributed in this soil.

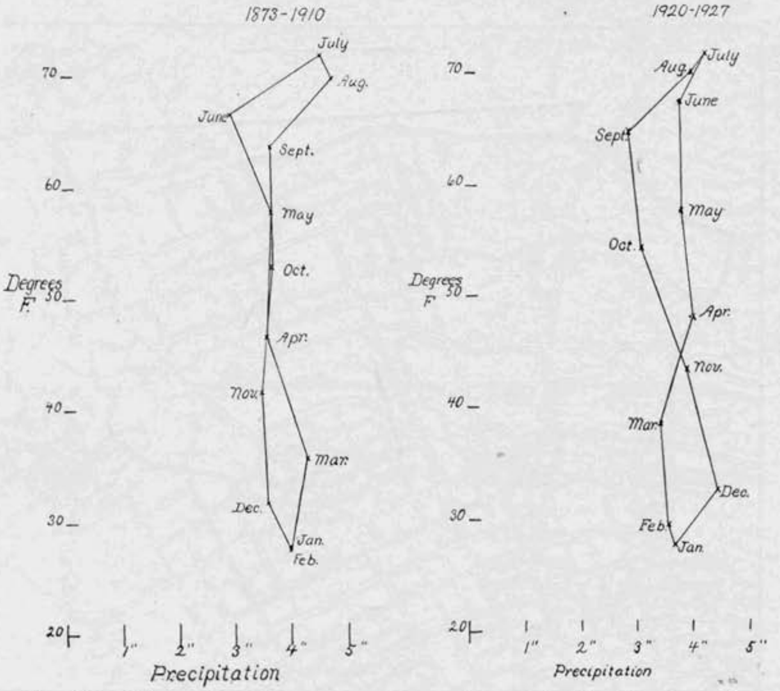

FIG. 34. Mean Monthly temperature and precipitation for the periods 1873–1910 and 1920–1927 at New Haven, Conn.

NATURAL CONDITIONS IN NEW HAVEN

The Asiatic beetle is indigenous to Japan and has flourished in the Territory of Hawaii, giving it a great range of latitude and a variety of natural conditions in those regions. It has in late years firmly established itself in Connecticut and some of the immediately surrounding sections. A brief summary of the natural conditions in New Haven is therefore pertinent to the subject and may aid in determining the possible future distribution of the insect in North America.

According to the definition of the life zones of the United States as given by C. Hart Merriam (1898) the coastal strip of Connecticut, approximately five to ten miles wide, and a strip of equal width along the Connecticut River to the northern boundary of the State are in the Upper Austral, the rest of the State being Transition. New Haven lies in the coastal strip and hence the area in which the Asiatic beetle is now found lies in the Upper Austral.

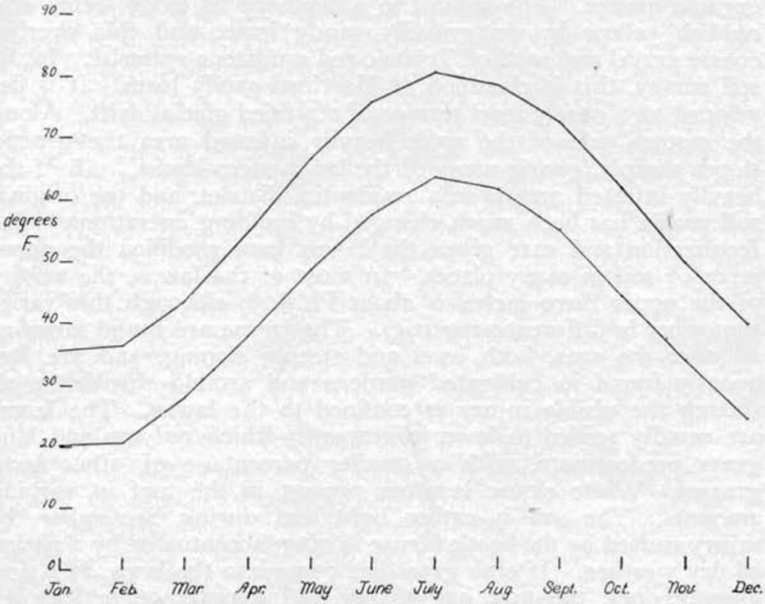

FIG. 35. Mean monthly maximum and minimum temperatures for the years 1873–1910 inclusive at New Haven, Conn.

The mean temperature and precipitation for two periods, 1873-1910 inclusive and 1920-1927 inclusive are given in Figure 34, the data being obtained from the New Haven station of the U. S. Weather Bureau. The period covering the years 1873-1910 gives what is more nearly the mean conditions for New Haven, and the period from 1920 to 1927 covers the first seven years during which the Asiatic beetle was known to be present here. The temperature means of the two periods are nearly the same, but the precipitation differs somewhat. In Figure 35 are given the mean maximum and mean minimum temperature for the years 1873 to 1910 inclusive and these adequately represent conditions for 1920 to 1927. Table 1 contains the data on which both figures are based.

The section of New Haven which is at present infested with the Asiatic beetle has a surface soil to a depth of about eight inches of brown sandy loam which contains two to three per cent. organic matter. The subsoil to a depth of 24 to 30 inches is a reddish yellow brown gravelly sandy loam, and this overlies coarse gravel and sand of Triassic red sandstone material. In the soil survey, this is classified as Hartford sandy loam. It is developed on a nearly level terrace of stratified glacial drift. Along the eastern side of the more heavily infested area the ground slopes sharply, giving many of the lawns steep banks. All of the heavily infested area is in a residential district, and the original soil profile has been much changed by building operations. The fertilization and care given the lawns have modified the upper layer of soil in many places. In most of the lawns, the acidity of the upper three inches is about Ph 6. 0, although this varies somewhat in different properties. The larvae are found in lawns all over the area, both level and steeply sloping, and are frequently found in cultivated gardens and around shrubbery, although the visible injury is confined to the lawns. The lawns are usually seeded to lawn mixtures in which red top and blue grass predominate, with a smaller percentage of other lawn grasses. White clover is often present in the turf in varying amounts. The soil is rather light and during September the injury caused by the beetle larvae is often accentuated by a period of dry weather. If crab grass has come into the lawn, as it frequently does, the turf has a very bad appearance in October regardless of the number of beetle larvae present or the weather conditions.

TABLE 1—MEAN TEMPERATURE AND PRECIPITATION AT NEW HAVEN, CONN.

	1873-1910 Inclusive.				1920-1927 Inclusive	
	Temperature					
Month	Mean Maximum Deg. F.	Mean Minimum Deg. F.	Mean Deg. F.	Precipitation Inches	Temperature Mean	Precipitation Inches
January	35.7	20.1	27.9	4.01	27.7	3.67
February	36.2	20.4	27.6	4.01	29.5	3.58
March	43.4	28.0	35.7	4.31	38.6	3.44
April	55.0	38.0	46.5	3.61	48.0	4.05
May	66.6	48.6	57.6	3.71	57.5	3.84
June	75.6	57.5	66.6	3.04	67.3	3.83
July	80.3	63.4	71.8	4.60	71.8	4.29
August	78.2	61.4	69.8	4.79	70.0	4.04
September	72.2	55.1	63.7	3.73	64.9	2.92
October	61.5	44.1	52.8	3.74	54.1	3.16
November	49.3	34.0	41.6	3.54	43.3	3.93
December	39.4	24.4	31.9	3.63	32.8	4.43

SYSTEMATIC POSITION

The genus Anomala belongs to the tribe Anomalini, sub-family Rutelinae, of the family Scarabaeidae. Arrow (1910) in classifying the Lamellicornia, uses the division of the Scarabaeidae into Pleurosticti and Laprosticti, the former having the posterior spiracles situated in the dorsal part of the chitinous ventral segments, as is shown in Figure 43 of this bulletin, and including the Rutelinae. The genus is readily defined by the characters given by Blatchley (1911) or by Casey (1915). In 1907 Schaeffer published a key to the adults of the genus Anomala inhabiting North America but not only does this key include species no longer placed in the genus but also separates species on the basis of color. The Asiatic beetle varies too much in color to permit the use of such a character as specific, and we have made no attempt to fit this species into that key. The adults may be readily separated from *Pachystethus lucicola* Fab., which they closely resemble in size and color, by the presence of a protuberance of the metasternum in the latter species, this protuberance being lacking in *Anomala*.

The larva of *Anomala orientalis* Waterh. may be easily distinguished from some other closely related forms. Böving (1921) has translated and published part of Schiodte's work on the larvae of Lamellicornia in which *Anomala aenaea* de G. is used as a type of the genus. Böving gave a systematic key to the larvae of the Scarabaeidae closely related to *Popillia japonica* Newm. and the larval characters of *Anomala orientalis* agree with the description of the genus Anomala as given by him except that the holes of the spiracular respiratory plate (Plate XVII) are not perfectly oblong, nor are the transverse rows perfectly regular, but the alternative is "angulate-rotundate" and "irregularly distributed" which is no closer to the true condition. A systematic description of the larva of *Anomala orientalis* is here given according to the formula of Schiodte and Böving for the sake of comparison with other Ruteline larvae. Some of the principal differences between the larva of *Anomala orientalis* and that of *Pachystethus lucicola* Fabricius and *Popillia japonica* Newman are mentioned here. A more complete description of the larva is given later in the morphological part of this bulletin.

Anomala orientalis WATERHOUSE

Epicranial suture with margins very slightly or not at all raised. Antennae with subapical joint equal in length to basal joint. Maxillary palpus with length of subapical joint to prebasal joint as 3 to 4. Length of tibia in proportion to femur about 4 to 5 (this varies because the length of the femur increases posteriorly; that is, the mesothoracic femur is longer than the prothoracic, and the metathoracic longer than the mesothoracic; whereas the respective tibiae more nearly equal each other in length). Claws of the third pair of legs shorter. Respiratory plate with oval holes placed in irregular transverse series (see paragraph above and Plate XVII).

The above description applies to the third instar larva. In the first instar the subapical-basal joint ratio of the antenna is about 2 to 3, and the tibiae are more nearly equal to the femora. In the second instar the basal antennal joint is slightly longer than the subapical joint, although not as much so as in the first instar, and the subapical-prebasal joint ratio of the maxillary palpus is 2 to 3.

The larva of *Pachystethus lucicola* is very similar in appearance to that of *Anomala orientalis* but may be distinguished by the following characters, which, in the case of *A. orientalis,* are constant in all instars. The frons of *A. orientalis* has a row of four setae close to the anterior margin, as shown in Figure 46. In *P. lucicola* there are two setae only, and these are in the position of the median two of *A. orientalis*. There are usually in *A. orientalis* about four large and two or three small setae in a more or less definite line each side of the epicranial suture posteriorly. In *P. lucicola* these setae are much less numerous. The labral setae also differ. In *A. orientalis* there are on the disc two setae, one each side of the mid-line, and posteriorly there are two fairly large and one or two minute setae each side of the mid-line. In *P. lucicola* there are two setae each side of the mid-line on the disc and one large seta on each side of the mid-line posteriorly. The claws of the third pair of legs in *Pachystethus* are the same length as those of the first two pairs, and the holes of the respiratory plate are angulate-rotundate and irregularly distributed. In *Anomala* the claws of the third pair of legs are shorter and the holes in the respiratory plate are oval in shape and arranged in irregular transverse rows. The two median rows of spines on the ventral side of the tenth abdominal segment in *Pachystethus lucicola* contain about ten spines each. In *Anomala orientalis* these two rows contain ten to sixteen spines each, 28 third instar larvae averaging 12.8 ± .2 right and 12.6 ± .2 left. The number of spines in these rows in some specimens would not in itself be sufficient to determine the species, but in most cases this character is dependable.

The larva of *Popillia japonica* Newman can be immediately distinguished from that of *A. orientalis* by the number, form, and arrangement of the spines on the tenth abdominal segment. In the former species there are about seven spines in each row, and the rows converge sharply anteriorly. The illustrations of *Popillia japonica* by Böving (1921) and Davis (1920) show this arrangement very clearly.

In comparing the above two species with *Anomala orientalis* I have used the morphological descriptions of Böving (1921).

Hayes (1928) has published a systematic description of the epipharynx of Lamellicorn larvae and a key to common genera based largely on the morphological differences in this structure.

The Asiatic beetle is included and can be readily differentiated from other common Scarabaeid larvae by the characters given.

DESCRIPTION OF STAGES

In the following pages there are given brief morphological descriptions of all stages of the insect. The primary purpose of this is not to present a detailed morphological study (and some of the details are therefore omitted) but such a description of the external anatomy as will enable one to distinguish the immature and adult stages from those of similar and closely related species. The material was all collected in New Haven and the larval and pupal descriptions were checked with reared material. For references to publications on the comparative morphology of the Scarabaeidae which form a basis for the description given here, the bibliography may be consulted.

THE ADULT

The original description of the adult by Waterhouse (1875) is as follows:

> "*Ph. campestri* affinis. Obscure cupreo-aenea, elytris plerumque flavo-variegatis. Capite fere ut in *Ph. horticola*, fronte crebre punctulata, clypeo angulis rotundatis. Antennarum clava praelonga nigra. Thorace parum convexo, antice angustato, sat crebre fortiter punctato, lateribus arcuatis, angulis posticis obtusiusculis, basi fere rotundato, marginato. Scutello arcuatim triangulari, punctulato. Elytris thoracis basi latitudinem aequantibus postice paulo ampliatis, ad apicem obtusis, depressiusculis, fortiter striatis, striis fortiter irregulariter punctatis, interstitii convexis, subtiliter obsolete punctulatis.
>
> "Long. 4-5½ lin.; lat. 2½-3 1–6 lin.
>
> "Var. a. Testacea, fronte thoracisque maculis duabus aeneis;tarsis piceis.
>
> "Var. b. Testacea, fronte thoracis limbo, elytrorumque fasciis duabus irregularibus aeneis.
>
> "Var. c. Aenea, elytris nigro-piceis, flavo-maculatis.
>
> "Besides the colouration this species varies much in form, the smaller specimens being more convex and slightly ovate; the sculpture of the elytra also varies, the interstices being almost rugulose in some specimens, whereas they are almost smooth in others.
>
> "*Hab.*—Kawachi; Nagasaki; Hakodadi. (Common in May and June)."

The adults collected in New Haven conform to this general description (Plate XVII). They are elongate-oval in shape and typically Scarabaeid. The greatest width of the body is at a point about three-fourths of the distance from the base of the elytra to the tip. The elytra are striate, and the striae are punctate. The pygidium is fully exposed. The female abdomen is larger in proportion to the rest of the body than is the male abdomen, and the latter tends to be slightly concave on the ventral side, whereas the former is convex. The horizontal row of setae on the eighth abdominal sternite follows a sinuate carina in the male, whereas in the female this row of setae follows the posterior margin of the sternite (Fig. 44). The labrum is concealed beneath the clypeus and does not appear in a dorsal view. The front legs are fossorial, though not extensively so developed. In the female, the prothoracic tibia is narrowly projected beyond the tarsal articulation, extending about to the base of the fourth tarsal joint. In the male, this projection is not quite as long and is much broader at the base, tapering more sharply (Fig. 39). The lamellae of the female antenna are distinctly shorter than the remainder of the antenna (Fig. 38), whereas in the male the lamellae are almost as long as the remainder of the antenna. These characters of the antenna and prothoracic tibia offer an easy means of determining the sex and are dealt with in more detail later.

The females are larger than the males, as the following measurements show, and both sexes show much variation. These adults were collected in the summer of 1927, pinned, and the measurements made in March, 1928. Fifty-seven females and 56 males, all taken in the act of copulation, were used (one male was lost). As an indication of the variation in width, the base of the prothorax has been used. This is more easily measured and less subject to distortion than the width of the elytra. The length was measured from the tip of the clypeus to the tip of the abdomen.

TABLE 2—LENGTH OF BODY AND WIDTH OF PROTHORAX OF ADULTS.

		Male		Female	
Length of entire body:	mean	9.05 ± .04	mm.	10.34 ± .07	mm.
	maximum	10.4	"	11.7	"
	minimum	8.2	"	8.9	"
	coefficient of variability	5.4		7.3	
Width of prothorax:	mean	3.97 ± .02	mm.	4.46 ± .03	mm.
	maximum	4.5	"	5.1	"
	minimum	3.5	"	3.9	"
	coefficient of variability	5.5		6.5	

The color of the adult varies from black to straw (about the honey-yellow of Ridgeway's color chart), with intermediate stages having black elytral bands and markings on the prothorax. The prothorax and head frequently have a bronze iridescence. In Figure 36 there are illustrated eight color types based on the color of the elytra and prothorax. These eight types vary within themselves and intergrade so that the individuals approximate only the types. There is no sexual color peculiarity, and both sexes show the same amount of variation. In the following table, the percentages of each color type are given of the 56 males and 57 females, of which the body measurements are given above, and of 259 miscellaneous specimens. This tabulation is approximately true of all the adults collected in New Haven. Types 6 and 7 are given together as they really represent one type having one elytral bar and two distinct black areas on the prothorax. The thoracic markings of type 8 vary from light brown to black.

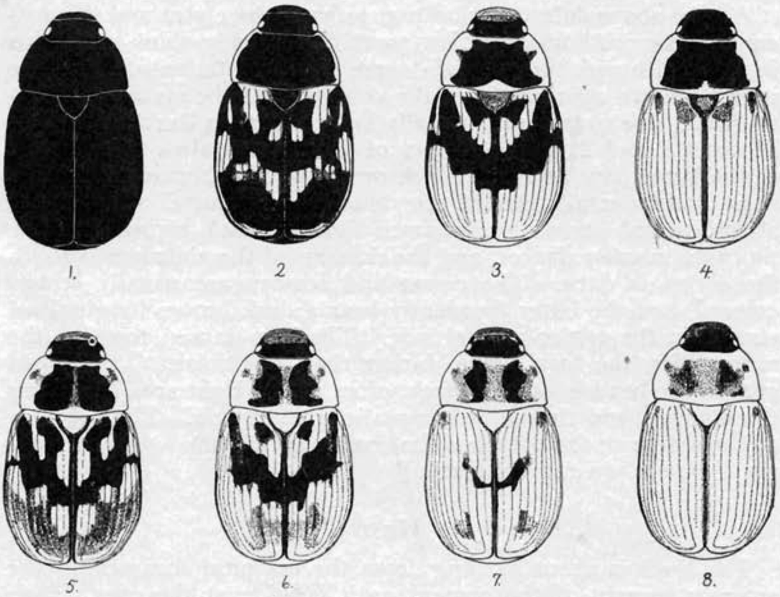

FIG. 36. Color variation of adults.

TABLE 3—COLOR VARIATION IN ADULTS.

Type	56 Males	57 Females	259 Miscellaneous	Total	Per cent
1	4	5	21	30	8.1
2	2	2	6	10	2.7
3	3	5	18	26	7.0
4	5	5	11	21	5.6
5	1	2	4	7	1.9
6 and 7	15	17	91	123	33.1
8	26	21	108	155	41.7
	56	57	259	372	100.1

The eight types are defined as follows:

1. Entirely black.
2. Thorax with one black mark, elytra with two black bars.
3. Thorax with one black mark, elytra with one black bar.
4. Thorax with one black mark, elytra entirely straw.
5. Thorax with two separate black marks, elytra with two black bars.
6. Thorax with two separate black marks, elytra with one black bar.
7. Thorax with two separate black marks, elytra with one black bar reduced.
8. Thorax with two separate dark marks, elytra entirely straw.

Almost half the adults have no elytral bars (types 4 and 8), and this is the most common type in New Haven. The coloration of adults found in other localities, where environmental conditions differ, may possibly not conform to the above, for environment causes regional variations in color among some beetles (see Tower, 1906), and this regional effect is not fixed genetically.

All the above data on coloration refer to the elytra and the dorsum of the prothorax. Other parts of the body show variations in color, although the general degree of pigmentation of the entire insect follows approximately the condition of the elytra and prothorax. The pygidium is usually light except in dark individuals of types 1 and 2, in the former of which it is always black and in the latter may be either black or straw. It frequently bears a dark band dorsally across the base. The ventral side of the abdomen and thorax varies from light to dark brown, but the thorax is usually darker, and the dorsum of the abdomen beneath the elytra is dark. The coxae and femora are usually straw-colored, and the latter frequently bear a dark brown longitudinal streak on the antero-ventral side. The legs darken towards the extremities, the tarsi being darker than the tibiae. The dorsal part of the head is usually black, often with a light area bordering the clypeus, and the latter is usually light brown. The lamellae of the antennae are dark but the remainder is pale. All individuals of type 1 are entirely black.

HEAD

The head is about as long from the occipital foramen to the anterior margin of the clypeus as it is wide at the eyes. It is normally partly withdrawn into the prothorax, and most of the occipital region is invisible.

The vertex (Fig. 37*a*) is not divided longitudinally by an epicranial suture, the dorsal part of the head capsule being fused into one piece. Except in the region of the occiput, normally overlapped by the prothorax, the vertex on the dorsal side is coarsely and thickly punctate. The occipital region, which is not distinctly separated from the vertex, contains a few fine punctures and has many fine setae laterally and ventrally. The vertex extends on the ventral side to the gula and is partly covered on this side by fine setae. On the lateral side of the head a short distance behind the eyes, there originates a suture which extends diagonally across the ventral side of the head to the anterior part of the gula. The head capsule does not readily separate along this line, and the suture may be a secondary structure rather than the occipital suture. On the dorsal side the vertex extends anteriorly to the suture separating it from the clypeus. According to Stickney (1923) this suture represents an invagination of the frons, and hence indicates the position of the arms of the epicranial suture. A pair of depressions along the line of this suture, one on each side near the lateral margin of the head, indicate the position of the anterior condyle (precoila) on which the mandible articulates. This condyle is on the ventral side of the clypeus (Fig. 38*b*). The frontal pits are on the ventral side of the head just lateral of the precoilae.

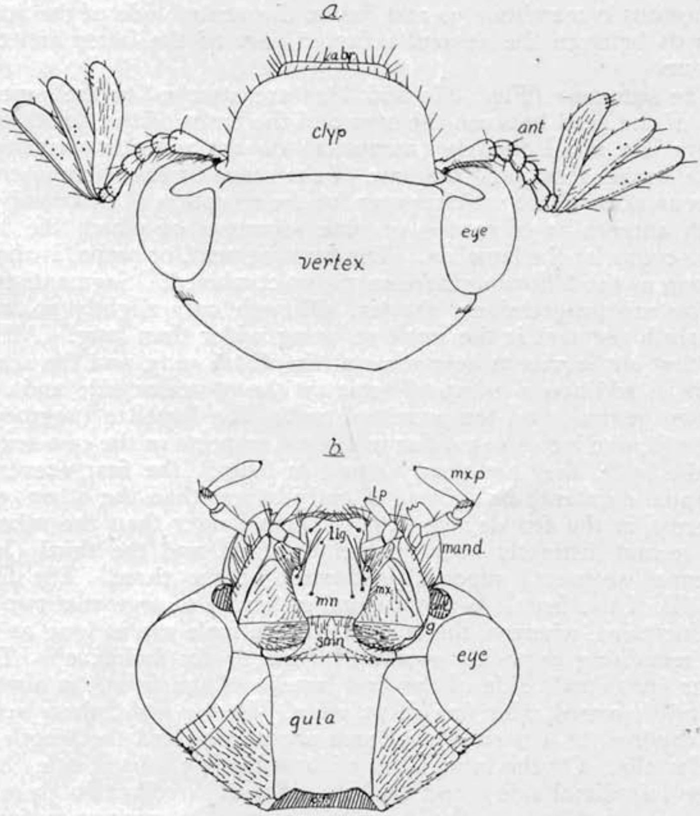

FIG. 37. The head, dorsal aspect above and ventral aspect below. *ant*, antenna; *clyp*, clypeus; *g*, gena; *labr*, labrum; *lig*, ligula; *lp*, labial palpus; *mand*, mandible; *mn*, mentum; *mx*, maxilla; *mxp*, maxillary palpus; *smn*, submentum.

From each anterior lateral angle of the vertex there extends posteriorly and partly over the eye a canthus. Between the eye and the mandible, on the ventral side of the head posterior to the antenna is the narrow gena. This is bounded posteriorly by a suture.

The clypeus (Figs. 37*a* and 38*b*) is approximately quadrate when viewed from the dorsal side. Its anterior margin is slightly upturned, and the anterior part of the clypeus is folded ventrally on itself. The dorsally visible part represents most of the postclypeus and its surface is coarsely and thickly punctate like the vertex. Anteriorly the punctures become more shallow. Along the lateral and anterior margins of the postclypeus there is a row of setae. The anterior part of this postclypeus is reflected ventrally and lies on the ventral side just over the labrum. The preclypeus is membranous and lies on the ventral side of the postclypeus between the ventral reflected part of the latter and the labrum.

The antennae (Figs. 37*a* and 38*e*) are attached to the ventral side of the head between the eyes and the bases of the mandibles. There is a small condyle (antacoila) on the anterior margin of the antennal fossa, and the base of the scape of the antenna contains an acetabulum which serves for the reception of this condyle. Each antenna is composed of nine segments of which the last three comprise the lamellae. The first segment, or scape, is about as long as the following three segments combined. Segments two to five are progressively shorter, although only slightly so, and the sixth segment is the smallest, being wider than long. All of the first six segments bear setae at the distal ends, and the scape bears in addition a group of setae on the posterior side and one or two ventrally on the proximal end. The lamellae (segments seven to nine inclusive) differ in several respects in the two sexes. In the male, they are nearly equal in length, the first (seventh antennal segment) being very slightly longer than the other two, whereas in the female, the first is much longer than the others, the second distinctly shorter than the first, and the third (last antennal segment) much the shortest of the three. The first lamella of the female is about equal in length to segments two to six inclusive, whereas, the lamellae of the male are as long as all the remaining segments combined (one to six inclusive). The outer (proximal) side of the first lamella of the female is almost entirely covered with fine short setae. In the male, these setae are confined to a narrow oval area about one-third the length of the lamella. On the inner sides of lamellae one (distal side) and three (proximal side), and on both sides of lamella two there is a longitudinal row of shallow pits, presumably sensory in function, near the dorsal margin. The male has about six pits in each row and the female about four. There is a row of short setae around the margin of each lamella in both sexes, and the sides of the lamellae are finely punctate. When these last three segments of the antenna are closed they combine into a club, the outer faces of the first and third being convex and the inner faces of both, together with both faces of the second, being flat.

The compound eyes (Fig. 37) are approximately hemispherical and situated on the lateral sides of the head. Each is partly

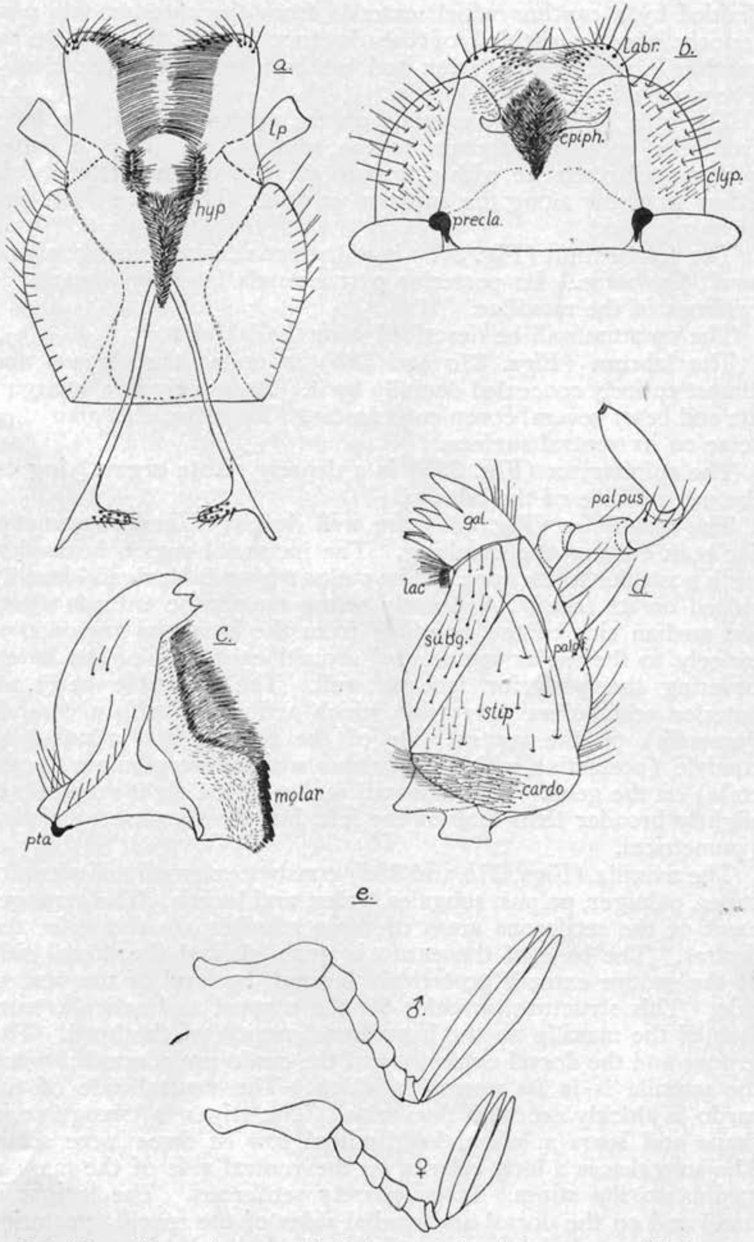

FIG. 38. a. Hypopharynx. b. Labrum and epipharynx. c. Right mandible, ventral aspect. d. Left maxilla, ventral aspect. e. Antennae, a male above, female below. *clyp*, clypeus; *epiph*, epipharynx; *gal*, galea; *hyp*, hypopharynx; *labr*, labrum; lac, lacinia; *lp*, labial palpus; *palpf*; palpifer; *precla*, precoila; *pta*, postartis; *stip*, stipes; *subg*, subgalea. Figures not all drawn to the same scale.

divided by a canthus which extends from the anterior side posteriorly about one-third of the distance across the eye. This canthus is part of the vertex and has been mentioned previously. There are no ocelli.

The gula (Fig. 37*b*) extends on the ventral side of the head from the occipital foramen to the submentum. It is a broad quadrangular sclerite with a smooth surface and no setae except a few in a row along the anterior margin. These are short and inconspicuous.

The submentum (Fig. 37*b*) is a distinct sclerite bearing several small fine setae. Its posterior part extends laterally toward the cardines of the maxillae.

The mentum will be described with the labium.

The labrum (Figs. 37*a* and 38*b*) is under the clypeus and almost entirely concealed dorsally by it. Anteriorly it is emarginate and bears several conspicuous setae. There are also many fine setae on its ventral surface.

The epipharynx (Fig. 38*b*) is a densely setose organ lying on the ventral side of the labrum.

The mandibles (Fig. 38*c*) are well developed and constructed for both cutting and crushing. The incisorial region bears two teeth posterior to the apex. The molar region is black and heavily ridged on its face. A densely setose membrane extends along the median side of the mandible from the incisorial region posteriorly to the molar region and around each side of the latter, covering the posterior face as well. The mandible bears an anterior acetabulum (preartis) which articulates with a condyle (precoila) on the ventral side of the clypeus and a posterior condyle (postartis) which articulates with an acetabulum (postcoila) on the gena. The incisorial region of the right mandible is slightly broader than that of the left, but the two are otherwise symmetrical.

The maxilla (Figs. 37*b* and 38*d*) consists externally of a cardo, stipes, palpiger, palpus, subgalea, galea, and lacinia. The arrangement of the setiferous areas of these sclerites are shown in the figures. The base of the cardo is grooved, and the dorsal side of the groove extends posteriorly beyond the level of the ventral side. This structure provides for the support and articular surface of the maxilla on the hypostomal region of the head. The groove and the dorsal extensions of the cardo are concealed when the maxilla is in its normal position. The ventral side of the cardo is thickly set with fine setae. The stipes is triangular in shape and bears a lateral longitudinal row of three large setae. The subgalea is a long sclerite on the ventral side of the maxilla median to the stipes. It is sparsely setiferous. The lacinia is small and on the dorsal and medial sides of the maxilla posterior to the galea. It bears many fine setae but no spines, teeth, or lobes. The galea comprises the apex of the maxilla and terminates in six prominent teeth of which four are ventral and two dorsal. Its lateral margin bears a group of setae near the base. The palpifer is a long sclerite lateral to the stipes and visible on both the dorsal and ventral sides of the maxilla. It bears many large setae. The palpus is four-segmented, and there are many minute sensory papillae on its tip. The fourth segment is the longest, followed by the second, third and first in the order given.

The parts of the labium (Fig. 37*b*) are fused together, the mentum and ligula not being separated by a suture. The mentum is broader anteriorly and bears on each side near the lateral margin a longitudinal row of three large setae. There is a row of small setae along each lateral margin and a small seta in each anterior lateral angle. On the ventral surface along each lateral margin of the mentum there is a row of short striae, about eighteen per row. The sclerite here called mentum has been termed the anterior part of the submentum by Kadic (**1902**) and Hardenberg (**1907**), the mentum being considered as folded back over it. The ligula is emarginate anteriorly and bears a small seta at each anterior lateral angle. On the ventral side there are many small setae along the anterior margin, except near the mid-line, and two longitudinal rows of fine mesad-pointing setae. These rows converge slightly posteriorly. The palpigers are apparently folded under the mentum and are visible from the dorsal side only. The palpi are set in depressions and each consists of three segments of which the third is the longest, the first next, and the second shortest. The tip of the palpus bears sensory papillae similar to those on the maxillary palpus.

The hypopharynx (Fig. 38*a*) is a thickly setose triangular lobe on the dorsal side of the labium. A pair of long chitinous bars unite under its posterior end and extend posteriorly to two medially directed setose sclerites. These bars and sclerites are the fulcrum hypopharyngeum and the pharyngeal sclerites.

The tentorium is essentially as described by Stickney (**1923**) for *Pelidnota punctata*. The corpotentorium is a narrow dorsally-arched bridge. The metatentorium expands posteriorly around the inner edge of the occipital foramen dorsally along the acciput and ventrally along the gula. It also follows the gular suture anteriorly as a tapering lamina along its entire length. The pretentorium arises at the end of the corpotentorium and is chitinized quite strongly at its base but soon becomes a narrow membranous thread. The anterior third is, however, strongly chitinized, although not large, and terminates between the base of the antenna and the precoila. The base of the pretentorium expands ventrally and laterally almost to the mid-line as a thin laminitentorium. This extends a short distance anteriorly, tapering towards its apex.

CERVIX

There are two lateral cervical sclerites on each side, one larger and anterior, the other smaller, posterior, and partly covered by the first. The anterior sclerite has a group of setae anteriorly and a few in the center. From its inner side at the anterior end a blunt projection extends into the neck cavity. The anterior end of this sclerite articulates with the head at the posterior lateral angle of the gula and its posterior end overlays the second sclerite in part. The latter projects freely from the cervical membrane and its attachment is shown by the broken line in the figure. Posteriorly it slightly overlaps the lateral end of the precoxal bridge of the prosternum. Dorsal to the anterior end of the first sclerite is a sub-triangular setiferous area which is not heavily chitinized.

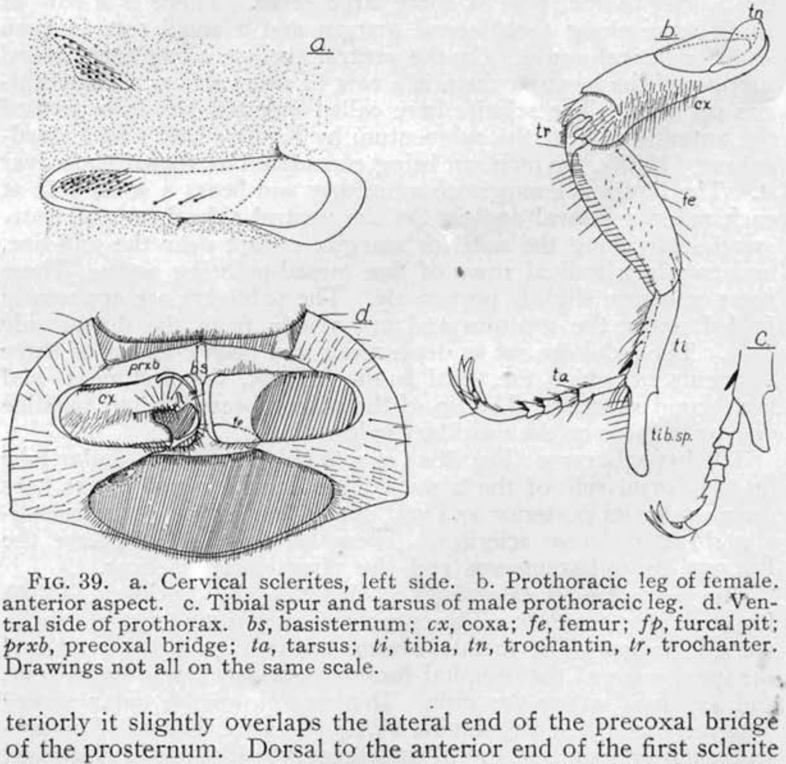

FIG. 39. a. Cervical sclerites, left side. b. Prothoracic leg of female. anterior aspect. c. Tibial spur and tarsus of male prothoracic leg. d. Ventral side of prothorax. *bs*, basisternum; *cx*, coxa; *fe*, femur; *fp*, furcal pit; *prxb*, precoxal bridge; *ta*, tarsus; *ti*, tibia, *tn*, trochantin, *tr*, trochanter. Drawings not all on the same scale.

THORAX

PROTHORAX

The prothorax, when viewed from the dorsal side, is about twice as wide as it is long at the mid-line. The anterior margin is concave, the lateral and posterior margins convex, and the dorsal surface is convex both longitudinally and horizontally. Anteriorly the prothorax is about half as wide as it is along the posterior margin. The dorsal surface is thickly punctate and bears about four small setate at each anterior lateral margin. The lateral margins are carinate. On the ventral side the pronotum extends to the precoxal bridge in front of the coxal cavities and to the sternum behind it. This part of the notum which extends on the ventral side is called the pseudopleurum by Crampton (1926). It is almost entirely covered by fine setae. The basisternum is broad anteriorly, extending laterally in the precoxal bridge, and narrows between the coxal cavities. The furcasternum comprises the posterior part of the sternum and extends laterally and dorsally in a broad shelf which is visible when the coxae are removed. This shelf bears the furcal pits. A suture separates the notum from the precoxal bridge in front of the coxal cavity, but posterior to the coxal cavity the extremity of the notum rests in a groove in the sternum and is not fused to it. The spiracle is in the membrane under the posterior ventral margin of the notum. On the ventral surface of the dorsum of the pronotum there is a short crescentic raised bar at the surface of contact of the trochantin of the anterior leg. The trochantin lies attached to the coxa at the anterior lateral margin and is not externally visible. The coxa has a crescentic ridge at its distal end on the anterior side and bears many fine setae on the lateral side. The trochanter is irregular in shape and firmly attached to the femur, articulating with the coxa. The femur is about the length of the coxa. It bears a longitudinal row of fine setae on the anterior lateral side and stronger setae along the anterior and posterior faces. There is also a longitudinal row of fine setae on the medial face. The tibia from its base to the tip of the spur is slightly longer than the femur. The spur is a prolongation of the lateral side of the tibia beyond the base of the tarsus and differs in the two sexes. In the female it is about as long as the three basal segments combined and spatulate in shape. In the male the base of the spur is wider and its length equal to the length of the basal two segments of the tarsus combined. The male spur tapers more than that of the female. The length of this spur as measured from the lateral projection opposite the base of the tarsus to the tip was for 57 females 0.87 ± 0.005 mm. and for 56 males 0.74 ± 0.004 mm. There is a longitudinal row of fine setae on the anterior face of the tibia and several more conspicuous setae along the medial face and on the inner face of the spur. There is a prominent blunt spine on the inner side of the tibia just above the base of the tarsus. The tarsus is five-segmented and terminates in a pair of movable claws. The first four segments bear terminal setae which, on the posterior side are short and spine-like. The anterior of the two claws is heavy and bifid at the tip. The posterior claw is smaller and simple. The tarsi of the sexes differ in a few respects. The male tarsus is heavier and the bifid claw more sharply curved than that of the female. Near the base of the fifth segment of the male tarsus there is a conspicuous mesad-directed tooth. On the female tarsus this tooth is very minute. Between the bases of the claws of both sexes there projects a conical papilla bearing two apical setae. The prothoracic coxae are capable of certain degree of movement and are not rigidly attached to the thorax. They project more from the body surface than do the other two pairs of coxae.

MESOTHORAX

The mesothorax is the least developed of the three thoracic divisions of the body. The notum is a single sclerite whose anterior region represents the scutum and whose posterior part the scutellum. The latter probably comprises at least two-thirds of the entire notum. A phragma projects into the body cavity from the anterior margin of the scutum, and along the mid-line there is an internal chitinous brace which extends from the phragma a short distance along the inner side of the scutum, being externally identified by an anterior longitudinal suture. The surface of the anterior part of the notum bears many fine setae set in pits in the chitin, but the posterior surface, exposed between the bases of the elytra, is bare, although pitted. At each anterior lateral angle there is an anterior notal wing process which supports the first axial sclerite and the dorsal end of the chitinous rod (parapterum?) found along the anterior margin of the episternum. The posterior notal wing process is not prominent. The sides of the scutum are reflected ventrally and give off two processes, one directed anteriorly and the other directed postero-laterally. The former lies over the metanotum and the latter projects under the axial cord of the elytron. There are many small setae at the top of the postero-lateral process and along its posterior margin. The scutellum has a posterior reduplication which is setiferous. The posterior basal angles of the elytra fit under the lateral margins of the scutellum. The axial region bears four small chitinous plates. The shape of these is not accurately shown in the figure, as they are irregular and a three-dimensional diagram would be required to give a true picture. The first of these axial sclerites curves from the anterior notal process ventrally and posteriorly to a notch in the ventral side of the elytron. The second is approximately triangular in shape with its base towards the scutum and its apex in an incision in the base of the elytron. The third is bent at an obtuse angle and lies along the region of the axial cord. The fourth, which is small and also sub-triangular in shape, lies just posterior to the second.

The pleural region is divided by a vertical suture into an anterior episternum and a posterior epimeron. The former is divided by a diagonal line of demarcation into a darker anterior area with a few setae along its posterior margin and a posterior lighter area devoid of setae. A short wing process (a continuation of the pleural ridge) which gives support to the elytron projects from the dorsal margin of the pleuron. A carina divides the epimeron into an upper approximately horizontal region and a lower vertical region. The anterior basal angle of the elytron rests on the upper horizontal area. The pleural coxal process extends from the ventral margin of the pleuron. Anterior to the episternum is a short, vertical rod (parapteron?) which extends to the anterior notal wing process.

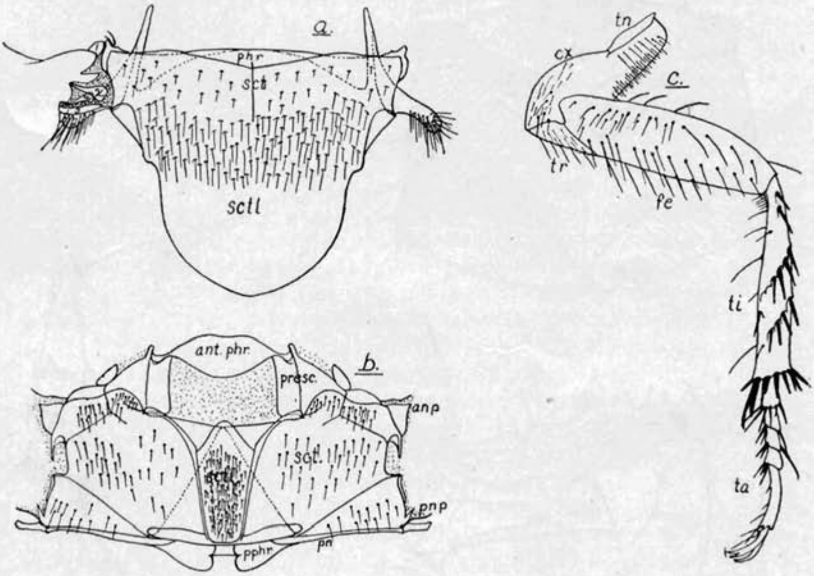

FIG. 40. a. Tergum of mesothorax. b. Tergum of metathorax. c. Mesothoracic leg, anterior aspect. The lateral scutal projections in "a" are displaced anteriorly. *anp*, anterior notal wing process; *ant phr*, anterior phragma of metatergum; *phr*, anterior phragma of mesotergum; *pn*, postnotum; *pnp*, posterior notal wing process; *presc*, prescutum; *sct*, scutum; *sctl*, scutellum; *1, 2, 3, 4*, axial sclerites. For other abbreviations see figure 39. Drawings not all on the same scale.

The sternum is rigidly attached to the metathoracic sternum along the posterior margins of the coxal cavities. The surface is thickly set with fine setae whose bases are in shallow pits in the chitin. The basisternum extends between the pleura anteriorly and narrows between the coxal cavities. If the coxae are removed the furcasternum, which bounds the coxal cavities medially, becomes visible, and the furcal pits are seen at the inner anterior angles of the cavities.

The legs of the mesothorax are not so strongly developed as those of the other two thoracic segments. The coxae are apparently slightly mobile, although not near so much so as those of the prothorax. The pleural coxal process forms the point of articulation of the coxa on the pleuron, and the narrow trochantin lies at the inner basal angle of the coxa. The latter is about two-thirds the length of the femur and is partly covered with fine setae as indicated in the figure. The trochanter is triangular in shape and setose and is firmly attached to the femur, articulating with the coxa. The femur is the longest segment of the leg, being slightly longer than the tibia. On the anterior side there are two irregular longitudinal rows of setae and on the posterior side a longitudinal row of fine setae. The tibia bears two diagonal rows

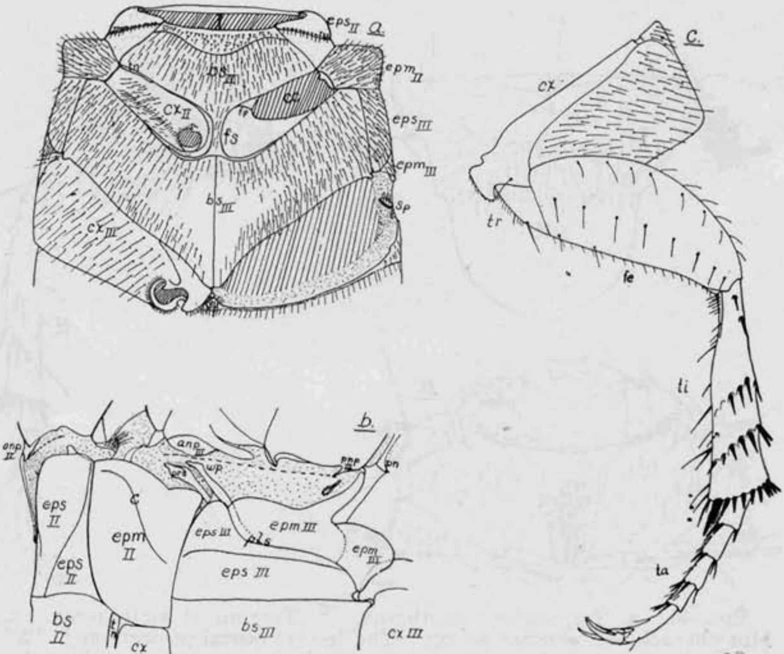

FIG. 41. a. Meso- and metathoracic sterna. b. Meso- and metathoracic pleura. c. Metathoracic leg, anterior aspect. *bs*, basisternum; *cc*, coxal cavity; *epm*, epimeron; *eps*, episternum; *fs*, furcasternum; *sp*, spiracle. The Roman numerals indicate the thoracic segments. For other abbreviations see previous figures. Drawings not all to the same scale.

of heavy setae on the anterior side and several small scattered setae on the posterior side. At the distal end of the tibia there are a number of short heavy spine-like setae on the anterior side, two prominent spines at the inner angle, and a few long setae on the posterior side. The anterior of the two spines at the inner angle is shorter than the posterior. The tarsus is five-segmented and similar to that of the prothorax. The claws are slightly smaller than those of the anterior tarsus and the sexes show no difference. The basal tooth on the fifth segment is small.

The elytra, when folded in repose, cover the dorsal part of the body from the anterior margin of the mesonotum to the anterior part of the pygidium except for the exposed part of the mesoscutellum which lies between their bases. There are eleven punctate striae on each elytron. The first of these striae lies close to the posterior margin (inner margin when the elytra are folded), and the second is very short. The eleventh, which lies close to the anterior margin, is also short. The anterior basal angle of the elytron is reflected ventrally to form a shelf which rests on the dorsal part of the epimeron. The posterior basal angle fits under the lateral margins of the scutellum, and the proximal part of the posterior margin fits into a groove in the metathoracic notum. The elytra meet along the dorsal mid-line except at the tips, a ridge along the margin of the left fitting into a groove in the right. The ventral side of the elytron has many fine setae on the proximal, distal, and anterior regions. The distal margin has the narrow thin membrane characteristic of the genus.

METATHORAX

The metathorax is much more highly developed than the preceding segment and its notum is more typical. The interpretation of the segment follows Snodgrass (1909 and 1927). The anterior border of the metanotum is the antecostal suture from which the anterior phragma projects anteriorly and ventrally into the body cavity. The prescutum comprises the anterior region of the notum and its heavily chitinized lateral areas are separated by a broad central membranous area which extends from the antecostal suture to the apex of the scutellum. The chitinous discs at the anterior lateral margins of the prescutum are for muscle attachment. At each anterior lateral angle of the notum is the triangular anterior notal wing process. The proscutum normally lies under the scutellum of the mesothorax. The scutum is separated into two lateral areas by a triangular scutellum whose borders are indicated by the broken line in the figure. The lateral margins of the scutum possess a pair of conspicuous indentations, and from the posterior lateral angles the posterior notal wing processes project. The axillary cords are posterior to these latter. From the anterior margin of the scutum extend the two converging parapsidal ridges between which is the pair of longitudinal grooves for the reception of the margins of the elytra. The scutum and the region between the parapsidal ridges bear many fine setae. The scutellum is a triangular area whose base meets the postnotum and whose apex touches the posterior border of the prescutum. Its boundaries are much more clearly indicated on the inner side of the notum than on the outer. The postnotum is a narrow sclerite extending laterally to the epimeron and forming the posterior border of the notum. Beneath it the posterior phragma projects into the body cavity.

The pleural region of the metathorax is divided by a pleural suture which runs approximately diagonally, giving more of horizontal orientation to the episternum and epimeron than vertical. The episternum lies below and anterior to the epimeron and is divided into two regions by a horizontal suture. The epimeron is divided into anterior and posterior regions by a light vertical suture. A dorsal process of the epimeron lies along the anterior margin of the lateral region of the postnotum and the postnotum meets the epimeron just posterior to the base of this projection. There are two wing processes which project dorsally from the pleuron, the anterior being the episternal parapterum which has fused to the episternum and the latter being the true pleural wing process, a continuation of the pleural ridge. On the ventral margin of the pleuron there is another inconspicuous projection of the pleural ridge which serves as a point of articulation for the leg. The metathoracic spirale lies in the membrane between the meso- and metapleuron. The pleural sclerites are setose except for the dorsal two-thirds of the anterior region of the epimeron.

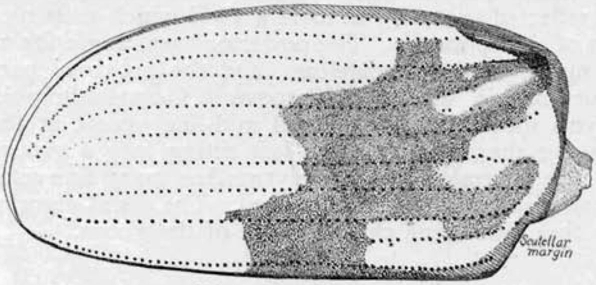

FIG. 42. Elytron.

The externally visible part of the sternum is the basisternum which extends between the episterna anterior to the coxa. A median longitudinal suture, which indicates the position of an internal chitinous lamella extending from furca to sternum, divides the basisternum. Except for a median nude area the basisternum is setose. At its posterior tip the sternum is inflected and to the inflected part is attached the membrane of the first abdominal segment. From the inflected part the furca extends into the body cavity. The furcal pits are not externally visible. At the posterior lateral angles of each basisternum is the small projection which fits into an acetabulum of the coxa.

There are four axillary plates in the membrane at the base of the wing which have been numbered according to Snodgrass (1927). In addition to these sclerites there is a median plate in the median region of the wing base.

The venation of the metathoracic wing is given according to Forbes (1922), and since the veins are labeled in the figure, no further discussion is necessary here. The distal part of the wing folds under the elytra, and the folding pattern is discussed by Forbes in the paper above cited. The anterior margin of the wing bears a row of small hooks and distal to it a row of small setae.

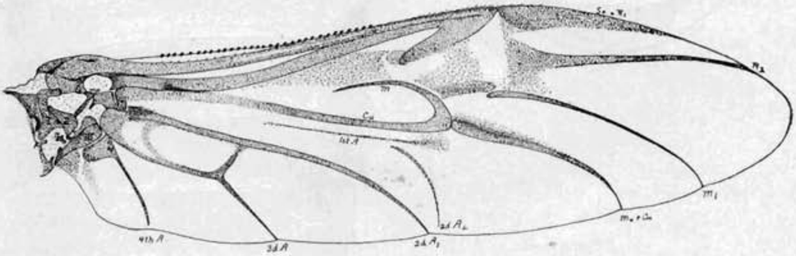

FIG. 43. Metathoracic wing. *A*, anal vein; *Cu*, cubitus; *M*, median; *R*, radius; *Sc*, subcosta; I, II, III, IV, axial sclerites.

The membraneous part of the wing anterior to the base of the costa usually folds back on it. At the base of the second anal vein there is a group of small setae.

The coxae of the third pair of legs lie rather rigidly in the coxal cavities with the anterior-ventral side in the same plane as the sternum. The anterior-ventral and posterior-dorsal surfaces are covered with fine setae. At the proximal end of the anterior margin there is a small notch or acetabulum into which a projection from the sternum fits. There is no trochantin. At its distal end the coxa terminates in a rounded "head" which projects over the triangular trochanter, and near the margin of the trochanter there is a rather large seta.

As in the case of the prothoracic and mesothoracic legs, the trochanter articulates with the coxa and is firmly attached to the femur. On its anterior side is a conspicuous seta at the inner margin.

The femur is large, approximately straight along the medial margin, and convex along the outer margin. Its anterior face is sparsely pitted and bears two longitudinal rows of setae, one near the outer margin and one just mesad to the mid-line. There are one or two conspicuous setae on the medial margin near the base. The posterior side of the femur is smooth and nude except for a row of fine setae along the inner margin. The tibia is slightly shorter than the femur and slender. There are two diagonal rows of spine-like setae on the anterior face and a similar row along the anterior side of the apex. At the inner angle of the apex there are two heavy spines of which the anterior is slightly over half the length of the posterior. On the posterior side and along the inner margin there are several scattered setae of medium size.

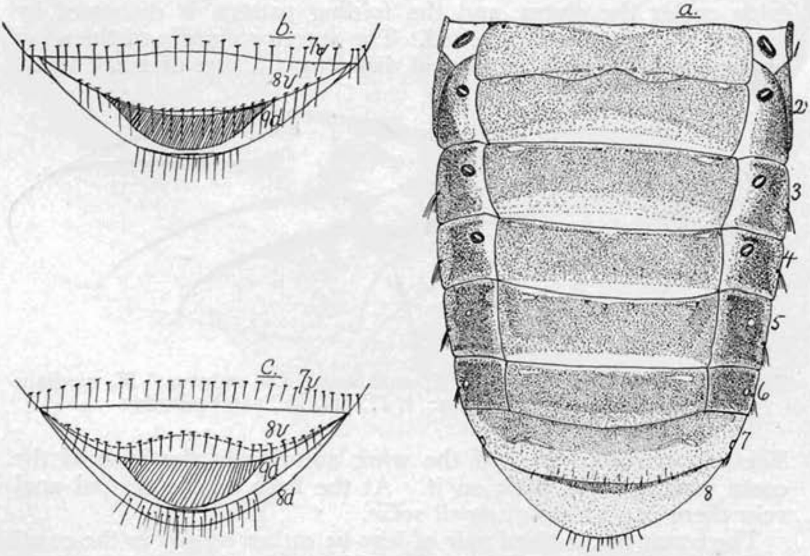

FIG. 44. Abdomen. a. Abdomen of female, dorsal aspect. v. Tip of female abdomen, ventral aspect. c. Tip of male abdomen, ventral aspect. The Arabic numerals indicate the segments. *d* signifies tergite and "*v*" signifies sternite.

The tarsus is similar to the mesothoracic tarsus in its essentials except that both claws are simple. In the other tarsi the anterior claw is bifid.

ABDOMEN

There are visible dorsally on the abdomen eight tergites and ventrally seven sternites. The first sternite is absent, and the ninth and tenth segments are concealed within the eighth. Tergites one to six inclusive are under the elytra and are weakly chitinized.

The dorsal part of segment seven is strongly chitinized and concealed beneath the tips of the elytra. The eighth tergite (pygidium) is fully exposed and the most strongly chitinized dorsal sclerite. This tergite slopes rather sharply downward to the tip of the abdomen and is slightly rugose. The tip of the abdomen bears a fringe of fine setae. The pygidium of the male tapers more sharply than that of the female.

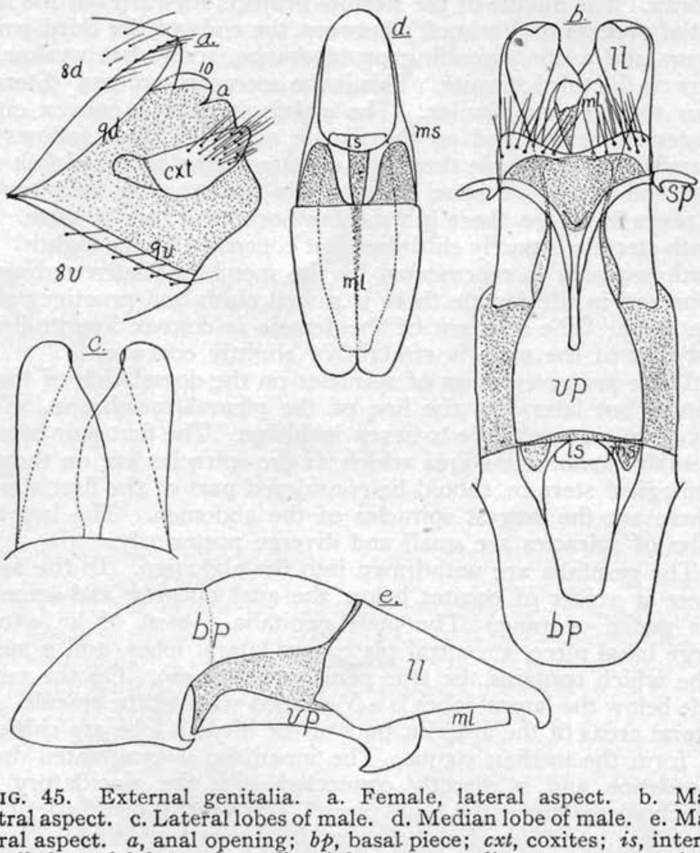

FIG. 45. External genitalia. a. Female, lateral aspect. b. Male, ventral aspect. c. Lateral lobes of male. d. Median lobe of male. e. Male, lateral aspect. *a*, anal opening; *bp*, basal piece; *cxt*, coxites; *is*, internal sac; ll, lateral lobe; *ml*, median lobe; *ms*, median strut; *sp*, spicule; *vp*, ventral plate. The Arabic numerals indicate the abdominal segment. and "d" signifies tergite, "v" sternite. The membranous parts are shaded,

The tergites do not all extend to the lateral margins of the abdomen, the pleural membrane being on the dorsal side in segments one to six inclusive. Segment seven is a completely chitinized ring, but in segment eight the pleural folds are at the lateral margins.

The first sternite, as mentioned above, is absent, and the second is narrow throughout most of its width, widening at the extreme lateral regions. The anterior margin of this sternite is concealed by the metathoracic coxae and a membrane connects it to the thorax. The middle of the sternite projects forward (as the interstitial process of Verhoeff) between the ends of the third pair of coxae and a corresponding protuberance, somewhat weaker, occurs on the third sternite. This is the accessory process. Sternites four to seven are similar. The eighth sternite is convex on the posterior margin and on the female a row of setae follows this margin. On the male there is a sinuate carina on the eighth sternite and a row of setae follows this carina. On sternites two to seven inclusive, there is a median horizontal row of setae. The ninth sternite is partly chitinized but concealed by the eighth. The tenth segment is represented by the membrane surrounding the anus and in the female there is a well chitinized proctiger above the arms. The sternum of the female is convex longitudinally, but that of the male is straight or slightly concave.

There are seven pairs of spiracles on the dorsal side of the abdomen but lateral to the line of the pleural membrane. These occur on segments one to seven inclusive. The first pair occur in a small membranous area which, if the spiracles are on the morphological sternite, should be considered part of the first sternite. These are the largest spiracles of the abdomen. The last three pairs of spiracles are small and diverge posteriorly.

The genitalia are withdrawn into the abdomen. In the female there is a pair of coxites below the anal opening and lateral to the genial opening. The male genitalia consist of an anterior large basal piece, a ventral plate, two lateral lobes, and a median lobe which contains the true penis or inner sac. On the ventral side below the lateral lobes is a Y-shaped sclerite, the spicule. The lateral areas of the anterior part of the median lobe are chitinized to form the median struts. The inner sac is evaginated during copulation and is directly connected with the ejaculatory duct which passes under the basal piece. The ventral distal part of the inner sac is chitinized and the proximal part is spinose. The median lobe lies between the paired lateral lobes and the ventral plate. Its lateral regions are chitinized. The genitalia of the male have been named according to Sharp and Muir (1912) and those of the female according to Tanner (1927).

THE EGG (PLATE XVIII)

When first laid the egg is white, ovoid, smooth, and measures about 1.2 mm. × 1.5 mm. After being in the soil a few days it swells and becomes more nearly spherical in shape. The following measurements of eggs of different ages indicate the relative size.

TABLE 4—DIMENSION OF EGGS

No. of eggs	Maximum width mm.	Maximum length mm.	Age
10	1.19 ± .002	1.51 ± .002	When laid.
	1.54 ± .013	1.82 ± .009	Same eggs after 10 days at 24° C.
7	1.59 ± .021	1.91 ± .043	13-15 days at 24° C.
8	1.58 ± .024	1.96 ± .041	Large eggs collected in the field.

It is essential that a certain amount of moisture be present to enable the eggs to develop. Under air-dry conditions they do not swell but dry out and die. The total period of incubation at 24° C. is 17 days, so the last two lots of eggs given in the table represent very nearly if not actually the maximum size. A photograph of the eggs is shown on Plate XVIII.

THE LARVA (PLATE XVIII)

There have been published in recent years the description of the larvae of several Ruteline beetles fairly closely related to *Anomala orientalis.* Böving (1921) gave a systematic and morphological study of the larva of *Popillia japonica* and *Pachystethus lucicola,* and Hayes (1927) described the immature stages and larval anatomy of *Anomala kansana.* Rittershaus (1927) published an account of the biology and morphology of *Phyllopertha horticola* and *Anomala aenea,* giving particular attention to the genitalia. In the following description, mention is frequently made of the setal arrangement, for the determination of the species may be more easy if the setal pattern is known.

There are three larval instars, and these conform to the Ruteline type. When first hatched the larva measures about four millimeters in length. During the first instar it attains a length of about eight millimeters. The second instar attains a length of about 15 millimeters, and the fully grown larva is 20-25 millimeters long. The following table gives the width of the head capsule measured at the widest part (just behind the antennae). Although there is some variation in this within each instar, it is not great enough to cause any confusion in the determination of the instar by measuring the head capsule.

When first hatched the larva is white except for the tips of the mandibles, the egg burster, and some of the setae, these being brown. The head soon darkens to a light brown color and the body darkens, due to the filling of the intestines when feeding begins. In the following description, the third instar was used, but the other two instars are essentially the same except for size, and where they differ in any important detail, this is noted in the description.

TABLE 5—WIDTH OF HEAD CAPSULE OF LARVA

No. of larvae	Instar	Width of head	
50	1st	1.15 ± .01 mm.	Measured day of hatching.
21	1st	1.19 ± .01	Preserved specimens from miscellaneous collections.
29	1st	1.17 ± .06	Preserved specimens not over 24 hours old when killed.
17	2d	1.96 ± .08	Preserved specimens from miscellaneous collections.
8	2d	1.81 ± .02	Measured 73-75 days after hatching. Reared in sod compost at 24°-25° C.
18	3d	3.07 ± .12	Measured 93 days after hatching. Reared in living turf at 24°-25° C.
20	3d	2.97 ± .03	Preserved specimens from miscellaneous collections.
7	3d	2.80 ± .04	Measured 116-118 days after hatching. Reared in sod compost at 24°-25° C.

HEAD

The head is slightly longer (from occiput to anterior border of labrum) than broad. There are no ocelli but the antenna and mouth parts are all well developed.

In the *epicranium* the Y-shaped epicranial suture extends from the occipital foramen to near the bases of the antennae where the arms become indistinct. The stem of the suture is about half the length of the frons. This stem is slightly thickened and from its inner side a tendon extends into the head cavity. The sides of the suture along the stem are very slightly if at all raised. The vertex is smooth and divided symmetrically by the epicranial suture. It extends laterally and posteriorly to the occiput. On the dorsal side the vertex bears a number of setae (Fig. 46). Along each side of the spicranial suture is a row of about seven setae extending from near the occiput to about opposite the middle of the frons. The number of setae in either row varies from five to eight in the all three larval instars. Between the end of this row of setae and the base of the antenna on each side is a group of two setae ("2" Fig 46.), which are constant and conspicuous, and there are numerous setae along the lateral sides of the vertex, the largest and most conspicuous of which are one near the base of the antenna ("1" Fig. 46) and one about midway between the occiput and antennae ("3" Fig. 46).

The *occiput* (Fig. 47) surrounds the occipital foramen laterally and dorsally. It is separated laterally on each side from the vertex by a suture and anteriorly from the postgena by another suture. The maxillariae, to which the cervix is attached, almost completely cover it. These are thinly chitinized sclerites which are folded back flatly against the posterior side of the head. Each bears near its latero-ventral angle a heavily chitinized point of articulation with the cervical sclerite of that side. This point of articulation is the odontoidea.

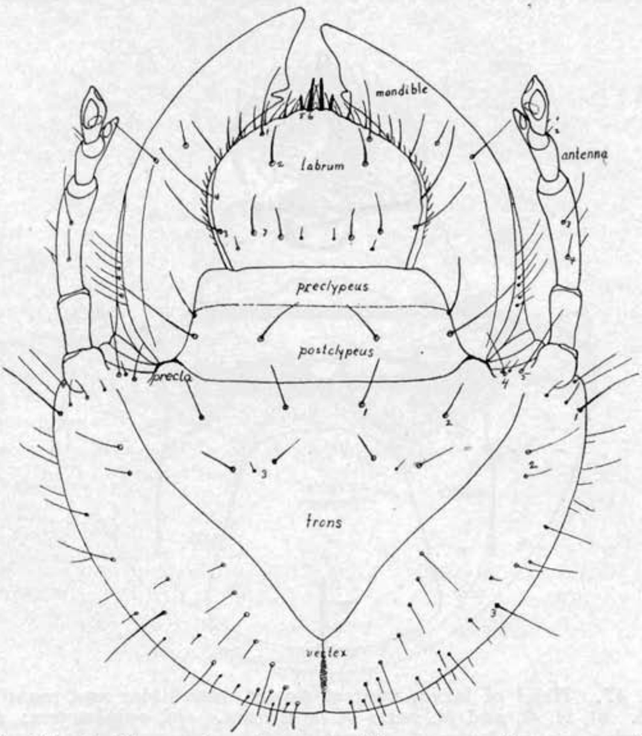

FIG. 46. Head of larva, dorsal aspect. The groups of more conspicuous and constant setae are numbered.

The *postgena* is more or less triangular in shape and separated from the occiput and gena by sutures. It bears at its median anterior angle the point of articulation with the maxilla, the paracoila or cardocondyle.

The *gena* is an area bordering the anterior lateral angle of the vertex and is found on the ventral side of the head capsule. It bears on its anterior margin the posterior point of articulation with the mandible, the postcoila. This is an acetabulum. There are several setae in the posterior part, two of which ("1" and "2" Fig. 47) are conspicuous and constant in position. The remainder are small and about eleven in number.

The occipital foramen is divided by a *tentorium* (Fig. 47) beneath which pass the nerve cords from the thoracic ganglion and above which passes the alimentary tract. The parts of the tentorium are probably as follows: The body (bt) constitutes the main part and divides the occipital foramen. The arms are represented by the thickenings marked "at" (anterior), "pt" (posterior), and "dt" (dorsal). The dorsal arms continue as thickenings of the capsule along the line of attachments of the maxillae and mandibles and the posterior arms extend back to the border of the foramen. The anterior arms extend forward slightly into the head cavity. A chitinous "brace" connects the dorsal and posterior arms, and a thin chitinous sheet connects the body of the tentorium with the posterior arms. The tentorium is not well

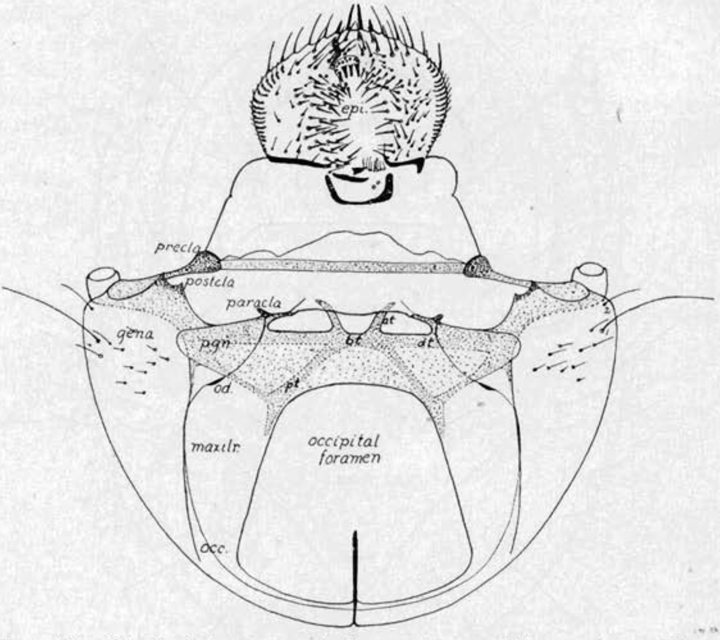

FIG. 47. Head of larva, ventral aspect, mandibles and maxillae removed. *at*, *bt*, *dt*, and *pt*, parts of tentorium. *epi*, epipharynx; *maxilr*, maxillaria; *occ*, occiput; *od*, odontoidea; *paracla*, paracoila; *pgn*, postgena; *postcla*, postcoila; *precla*, precoila.

developed, and all the parts here described may not be homologous with those of the adult.

The *frons* (Fig. 46) occupies the region between the arms of the epicranial suture and the fronto-clypeal suture, being triangular in form. There are several small pores scattered over its surface, and it bears several prominent setae. On the anterior part are six setae constant in position and present in all instars. Of these six one pair is close to the anterior margin and near the mid-line ("1"). Lateral and somewhat posterior to each of this pair is another seta ("2"), about midway between "1" and the epicranial suture. Between the base of the antenna and the precoila on each side are two large setae ("4" and "5") and one or two minute setae. In the middle of the frons are four large and constant setae, one pair each side of the mid-line ("3") and there is frequently a minute seta associated with each of these pairs. The frons bears near each lateral anterior angle the anterior condyle on which the mandible articulates, the precoila.

The *antennae* are four segmented and each is borne on a conical projection of the vertex. The first segment is short and bears no setae. The second is the longest of the four and bears two dorsal setae ("3" and "4" Fig. 46) and three or four ventrally. The third segment is short and terminates in a short conical projection on the inner side. There are two setae ("1" and "2" Fig. 46) on its ventral side. The conical spur on the median side of the distal end bears an oval sensory area on its outer surface. The fourth segment is conical and bears no setae. There are three sensory areas present on this segment, one large and oval in shape on the dorsal surface, one small and more or less quadrangular on the ventral surface, and one small and oval on the inner surface near the apex (Fig. 46). The ratios of the length of the segments has been used by Böving in describing Ruteline larvae and for the third instar of *A. orientalis* are approximately as follows: Subapical to basal segment 1:1; apical to basal segment 1.3:1; total length to basal segment 5:1.

The *clypeus* (Fig. 46) is approximately rectangular in shape and a little over twice as wide as it is long. It is divided into an anterior membranous preclypeus and a heavily chitinized postclypeus, but there is no dividing suture. The post-clypeus has a slightly rugose surface which contains many scattered "pores", and bears six prominent setae, one each side of the mid-line near the base, one each side near the middle of the lateral margin, and one at each anterior lateral angle. The preclypeus is asymmetrical, the left anterior angle being more prominent than the right.

The *labrum* (Fig. 46) is asymmetrical as shown in the figure. The dorsal surface is rugose and contains many "pores". There are eight prominent setae on the disc, two near the anterior margin ("1"), two a little anterior to the center ("2"), and four ("7") near the posterior margin. The latter are grouped in two pairs, one pair each side of the mid-line, and close to each pair there are usually one or two minute setae. On each side of the labrum and on the posterior half are two large setae ("3" and "4"), the anterior of which is in a groove which runs longitudinally along the side. At the tip of the labrum are four heavy setae of which the outer two are about one-half the length of the inner two. Along each side and posterior to these apical setae is a row of about five setae. The setae around the edge of the labrum are set in slight depressions, which gives a crenulated appearance to the margin. The central setae ("2") on the disc are set in deep depressions, and the posterior setae ("7") in slight depressions.

The *epipharynx* (Fig. 47) has been described by Hayes (1928). It covers the ventral side of the labrum and is devoid of setae in the center. On each side of this nude area are several short heavy setae arranged in three more or less regular rows and all pointing centrally. Lateral to these are several very small setae. Anteriorly is a small papilla (distal sensory area) bearing three spines and, just anterior to the spines, a transverse row of eight or nine "pores." The area between the papilla and the tip of the labrum is covered with setae and contains a shallow longitudinal depression which extends from the right side of the papilla to the anterior margin of the labrum. Extending medially from each posterior lateral angle of the labrum and on the ventral side is a narrow chitinous plate, the torma. The one on the left curves anteriorly at its apex and posteriorly at its base. The right one is nearly straight. Between these lines a short conical chitinous papilla (sensory cone), and posterior to this cone is a heavily chitinized narrow transverse plate which is attached at its lateral end. Between the cone and the left torma is a transverse row of very fine short setae. Still further posteriorly is a lightly chitinized U-shaped band and two pores (clypeal sensillia). These structures posterior to the tormae are really on the ventral side of the clypeus. On the lateral side and extending from the posterior margin about two thirds of the distance to the apex is a row of chitinous striae, about 16 in number, each of which is accompanied by a small seta at its outer end (Fig. 47). The tips of the setae of these two rows are visible from the dorsal side.

The *mandibles* (Fig. 48*a*) are asymmetrical, the right being more acutely pointed than the left, having a shallower incision separating off the dentes, and having a differently constructed molar region. The tips of the mandibles and the molar regions are black, the remainder brown. The incisorial edge (gnathapex) of each mandible is slightly concave with one dentes (gnathodentes) posteriorly. On the dorsal surface of the mandible and about one-third the distance from the apex to the base is a conspicuous seta, and lateral of this is another larger seta. The base of the mandible is three-sided. The outer face bears a longitudinal ridge ventral to which is a group of about seven setae and dorsal to which is a row of about ten pores. In the first and second instars, however, this face is smooth, although the setae are present. The ventral face bears a more or less oval stridulatory area of transverse ridges. These areas are similar in shape on each mandible (Fig. 48*a*). The outer basal angle of the ventral surface of each mandible bears a group of about five very small setae distal to the posterior condyle (postartis). This condyle articulates in an acetabulum (postcoila) on the gena. The anterior (or dorsal) articulation is by means of an acetabulum (gnathacetabulum or pre-artis) on the anterior dorsal face and a condyle (anterior condyle or precoila) at the posterior lateral angle of the clypeus. The inner posterior (proximal) part of the mandible is the molar region. This has been figured for two species of Scarabeidae by Böving and its structure used to distinguish them. The molar regions of the mandibles meet the hypopharyngeal chitinization as well as each other. On the ventral side of each mandible and close to the molar region is a lobe which meets the hypopharynx. The right molar region consists of four granulose surfaces separated by grooves. The distal three constitute the crown (according to Böving) and the proximal one the heel or calyx The first lobe of the crown (cr) is in some specimens oval and is so drawn, but in many specimens of all instars it is very irregular. The other two lobes of the crown (cr_2 and cr_3) are elongate and curved, and the heel or calyx (ca) is flat, approximately oblong and about twice as broad as long. The dorsal posterior angle of the heel extends as an obtuse conical projection, and the posterior side of the face is not parallel with the distal but slopes in slightly toward the distal side. The proximal side of the molar region of the right mandible bears a dorso-ventral row of setae. The left molar region is projected medially at the anterior end, this projection meeting the sinuate upper part of the hypopharyngeal chitinization. The inner face of the molar region bears two anterior incised rugulose surfaces and a posterior smooth sub-triangular area. Projecting from the dorso-anterior angle of this latter area is a membranous lobe (hamus) from the apex of which runs a row of setae which extends around the posterior margin of the molar region. The dorsal and outer surfaces of the mandibles are rough, but the ventral surface, except for the stridulating area, is smooth. The exterior tendon of each mandible is attached along the posterior edge of the outer face, and the flexor tendon is attached along the posterior edge of the molar region. A membranous area (trochantin of the mandible) lies between the base of the mandible and the base of the antenna.

The *maxillae* (Fig. 48*d* and *e*) are paired structures articulating with the head capsule by means of an acetabulum (parartis) on the basicardo and a condyle (paracondyle) on the postgena. The galea and lacinia are fused into one conical lobe, the mala, the outer part representing the galea and the inner the lacinia. Along the medial side and near the apex of the lobe are three fixed large spines in a longitudinal row, the largest of the three being the anterior and the smallest the posterior. On the dorsal side of the lobe are three more or less parallel rows of setae running obliquely across with a few scattered setae (about seven) posterior

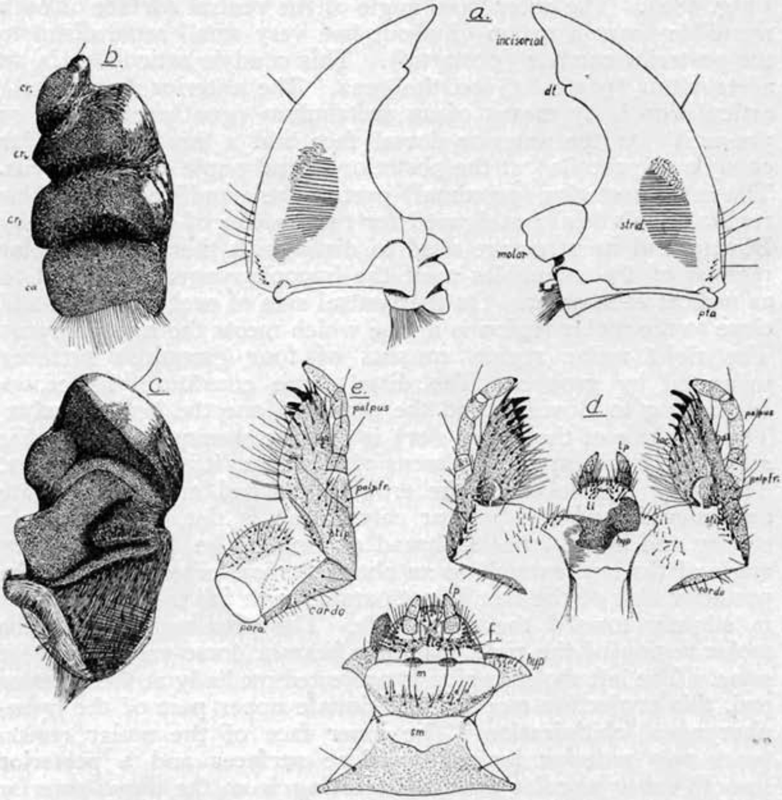

FIG. 48. Mouth-parts of larva. a. Mandibles, ventral aspect. b. Molar region of right mandible. c. Molar region of left mandible. d, Maxillae, dorsal aspect. e. Left maxilla, ventral aspect. f. Labrum, ventral aspect. *ca*, calyx, or heel; *cr.*, cr_2, cr_3, crown of molar of mandibles; *dt*, tooth of mandible; *gal*, galea; *hyp*, hypopharynx; *lac*, lacinia; li, labium; *lig*, ligula; *lp*, labial palpus; *m*, mentum; *paplfr*, palpifer; *pta*, postartis or posterior condyle of mandible; *sm*, submentum; *stip*, stipes; *strid*, stridulating area of mandible.

to them. The anterior of these three rows contains seven heavy setae, the next row eight more slender setae, and the posterior row about five slender setae. There are several short setae at the lateral basal angle of the lobe on the dorsal side. On the ventral side of the lobe is a longitudinal row of about six setae. Anterior to this row and at the apex are two heavy setae, and other setae are found as indicated in the figure. There are a few setae on the ventral side on the stipes and on the base of the palpifer. A small elongate sclerite medial to the stipes is the parastipes. It bears a row of about five minute setae. On the dorsal side of the stipes is a row of from five to seven (usually five or six) strong anteriorly directed hooks which comprise the maxillary part of the stridulatory apparatus. These rub against the corrugated area on the ventral side of the mandible. The cardo is divided into two sclerites, a basicardo and a much larger disticardo, both of which bear a few setae. The basicardo bears the acetabulum (parartis) of the maxilla. On the dorsal side the proximal part of the maxilla is membranous and bears many minute setae. On the ventral side this proximal region has a chitinized area bordering the cardo and a lightly chitinized setiferous area medially. The maxillary palpus is four-segmented and is borne on a projecting palpifer. The palpifer is setiferous and there is one seta on the ventral side of the first segment of the palpus, one anteriorly on the ventral side and one laterally on the second, two on the third placed similarly to those on the second. The apex of the fourth segment bears a number of minute sensory papillae. The relative lengths of the segments from basal to apical consecutively bear the following ratio, approximately: 1:2: 1.5: 2.5 (in the third instar). The relative lengths of these segments varies a little in the other instars, but the basal segment is always the shortest, the sub-apical next, the second segment next, and the apical segment longest.

The parts of the *labium* (Fig. 48*f*) are fused into a single structure. The submentum is approximately trapezoidal in shape and well chitinized over the basal two-thirds. There are four setae present, one large seta near each basal angle and one small seta in each apical angle (these latter are absent in the first instar). The mentum is broader at the apex than at the base and is much wider than long. It bears a chitinous band across its base on which are one pair of prominent setae near the mid-line and between and lateral to them several smaller setae. In the first instar there is only one small seta present lateral to the large setae. The ligula, representing the fused distal parts of the labium, is approximately conical with a pair of palpi borne on the ventral side near the apex. Near the mid-line and on the posterior border of the ligula are two small oval chitinous areas. The area around the base of each palpus on the ventral side is heavily chitinized and setiferous, and the tip bears many setae. A little dorsal to the apex of the ligula is a depression with a pore in its center. The palpi are two-jointed and the apex of the terminal joint bears a number of minute sensory papillae.

The *hypopharynx* (Fig. 48*d*) lies on the dorsal side of the labium. Its anterior part is asymmetrical and heavily chitinized, projecting anteriorly on the right side, the hypopharyngeal chitinization of Böving. Against this chitinization the molar regions of the mandibles act, the anterior part of the left molar meeting the left side of the anterior projection of the chitinization. There is a group of small setae at each anterior angle of the hypopharynx and a row (approximately longitudinal) of setae on each side of the base of the chitinization. The left row is longer and curves medially at its anterior end. The right row is short and follows the edge of the chitinization. The sides of the hypopharynx as it passes into the pharynx are slightly chitinized.

CERVIX

The most important part of the cervix consists of the sclerites, not separated from the rest of the cervical region by sutures, which extend from the episternum of the prothorax to the maxillariae, forming a support for the head, one sclerite on each side. The remainder of the cervix is membranous and devoid of setae except in the mid-ventral region where a group of setae belonging to the prothorax extends upon the cervical membrane.

THORAX

On the dorsal side the thoracic segments are divided into annulets. There are three of these on each segment, but the division between the first two of the prothorax is very faintly indicated. Figure 49 is a diagram of the body of a third instar larva and shows these annulets and the setal arrangements. The thoracic segments are indicated by Roman numerals. The third annulet of the prothorax and the second annulet of the meso and metathorax are devoid of setae, but the other annulets are setiferous.

There are certain setiferous areas laterally on the thorax, these areas being on slight protuberances of the integument (Fig. 49). On the prothorax these areas, except for one on the posterior-ventral angle of the pleuron, are poorly defined. On the meso- and metathorax there are on each side four such areas, one between the second and third annulets; one, circular in out-line, ventral to the first and between the ends of these annulets; two smaller, ventral to the second.

The prothorax bears a pair of spiracles (these belong phylogenetically to the mesothorax) close to the posterior margin,

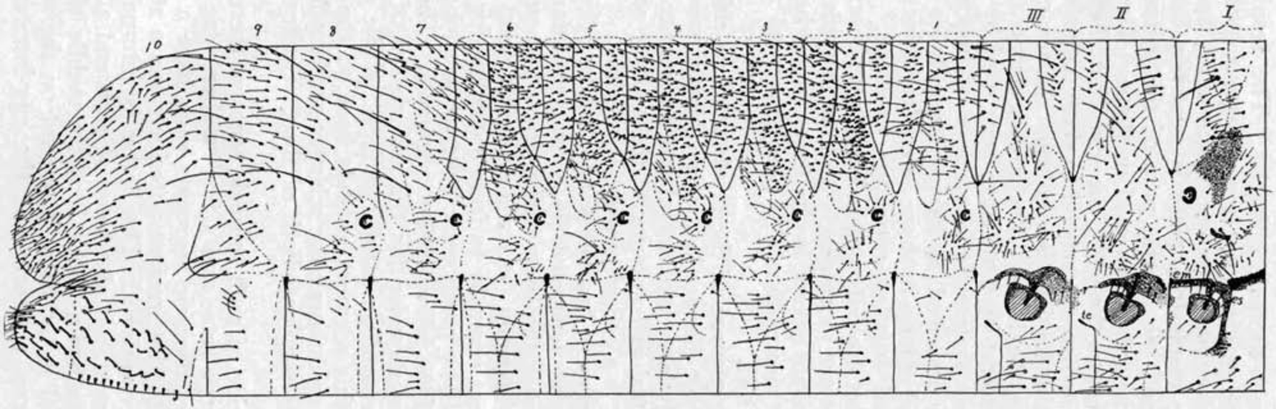

FIG. 49. Diagram of larva right side, head and legs removed. The upper margin represents the dorsal mid-line and the lower margin the ventral mid-line. The Roman numerals indicate the thoracic segments, the Arabic numerals the abdominal segments; *em*, epimeron; *es*, episternum; *te*, tendon.

these being the only thoracic spiracles. The respiratory plate (peritreme) of the prothoracic spiracle opens posteriorly, the reverse of the abdominal spiracles which open anteriorly. In the first instar the respiratory plate is relatively larger than in the other instars and the central part of the spiracle relatively small and more triangular than oval in shape. The prothoracic spiracle is the largest on the body, the seventh and eighth abdominal spiracles next in size, the second to sixth inclusive abdominal next, and the first abdominal is smallest. In the center of the respiratory plate is the bulla. The arrangement and shape of the holes of the respiratory plate have been used by Böving, following Schiödte, as systematic characters of importance. The genus *Anomala* is described as having these holes arranged in transverse rows and oblong in shape in contradistinction to irregularly arranged and angulate-rotundate in shape. In *Anomala orientalis* these holes are only approximately as described for the genus *Anomala* but are more nearly so than irregularly arranged and angulate-rotundate except in the first instar where they conform to the latter description. A photograph of a spiracle is shown on Plate XVII.

There are on the pleuron of the prothorax two chitinous plates near the spiracle (not distinct in the first instar, however). One of these is relatively large and dorsal and anterior to the spiracle. The other lies ventral and anterior to the spiracle and is a small bar. Just above it is a conspicuously large seta.

Each thoracic segment has two small sclerites lying just above the coxal cavity and separated by a perpendicular suture. A phragma projects into the body cavity from this suture. These sclerites are the episternum (es) and epimeron (em) and at their junction they project ventrally to form a condyle for the articulation of the coxa. The prothoracic sclerites are longer and narrower than those of the following two segments. The prothoracic episternum forms a shoulder for the articulation of the cervical sclerite and then extends ventrally in front of the coxal cavity. The epimeron of this segment extends back to the mesothorax. On the meso- and metathorax the sclerites are broader but not as long. On all three segments both of these sclerites bear two to four small setae.

On the ventral side of each thoracic segment there is a median group of rather large setae and a few smaller setae lateral to it. The meso- and metathoracic segments each have a light curved transverse fold in the integument anteriorly and a straight linear transverse ridge posteriorly. This latter is internal and serves for muscle attachment. It also bears at each end a short tendon (te) to which is attached a muscle from the middle of the pleuron.

In the first larval instar there is present on the middle of the metathoracic pleuron on each side the egg-burster. This has been very well described as to form and function for other Scarabaeidae by Rittershaus (1927). It consists of a conical sharply pointed protuberance bearing a slender pointed spine on the posterior side of the apex (Fig. 50*c*) and serves as a point for the application of pressure from within when the larva breaks the egg chorion in order to hatch. It does not act as a means of cutting the chorion. This egg-burster is cast off at the first molt.

The thoracic legs are illustrated in Fig. 50*a*. Those of the prothorax are shortest and those of the metathorax longest. This difference in length occurs mainly in the coxa, although the more terminal part (except the tarsal claw) also shows a progressive increase in length from prothorax to metathorax. Each leg is composed of five segments, coxa, trochanter, femur, tibia-tarsus and tarsal claw. The principle articulations of the leg occur at the coxa-pleuron and coxa-trochanter joints, and in the prepupal stage the legs are folded at the latter joint. The proximal edge of the coxa bordering the thorax is heavily chitinized anteriorly where the coxa articulates on the thoracic sclerites (Figs. 49 and 50*a*), but this chitinization diminishes on each side and is practically absent posteriorly. All the leg segments except the tarsal claw bear numerous setae, but the claw bears two only, one on the median side and one on the postero-lateral side. This claw is heavily chitinized at the tip but quite fleshy proximally. The third tarsal claw is much shorter than that of either the meso- or prothorax, a character used in distinguishing *Anomala* from allied genera (see Böving 1921).

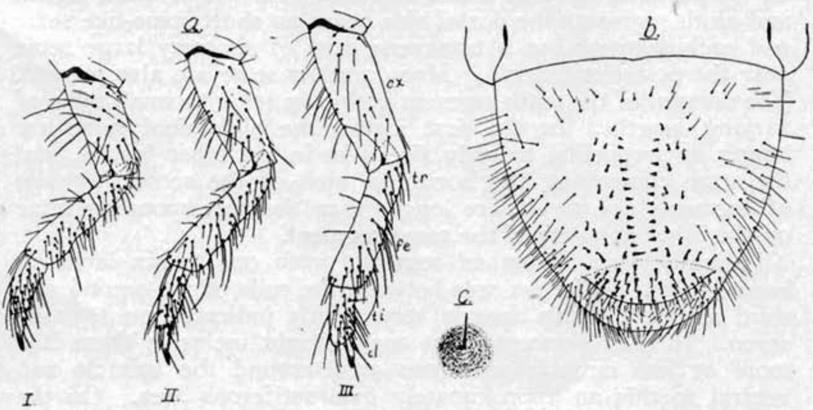

FIG. 50. a. Larval legs, all drawn to the same scale. b. 10th abdominal segment of larva, ventral aspect. c. Egg-burster of larva. *cl*, tarsal claw; *cx*, coxa; *fe*, femur; *ti*, tibia-tarsus; *tr*, trochanter. The Roman numerals indicate the thoracic segments.

ABDOMEN

There are ten visible abdominal segments of which the first six are divided on the dorsal side into three annulets each, but the last four are simple. These annulets tend to confuse the limits of the segments, but Figure 49 shows what appears to be correct according to the internal muscle attachments. Each annulet of the first six segments except the first of segment one and the third of segment six bears a transverse row of fairly prominent setae posteriorly and a large number of very short spine-like setae, the general arrangement being similar on the corresponding annulet of each segment. In the two excepted annulets the setae are irregularly arranged. The usual number of setae on the anterior annulet is about ten, on the median annulet about eighteen, and on the posterior annulet about fourteen. On the seventh, eighth and ninth segments the dorsal side bears no short spine-like setae and each segment has a transverse row of six very large setae near the posterior margin. Many smaller setae are also present. The dorsum of the tenth segment is thickly set with small setae of varying lengths. In the first instar, the abdominal setae are longer in proportion to body size than in the other instars, and the setae comprising the horizontal row of the second annulet of segments one to six are longer than the corresponding setae on the other annulets of the same segment.

Laterally each abdominal segment from one to six inclusive bears an oval setiferous area between the ends of the second and third annulets. This area is very faintly indicated on segment seven. In each segment from one to eight inclusive there is a more or less circular setiferous area around the spiracle and ventral to this an approximately oval setiferous area. On the ninth segment there is a triangular setiferous area on each side, the ventral margin of this area being the line separating the ventral and pleural regions of the segment. All these setiferous areas are protuberances or folds of the integument. At each end of the anal slit on the tenth segment is a small group of setae which are somewhat longer than those on the dorsum. There are eight pairs of abdominal spiracles, one pair on each of the first eight segments. The respiratory plates of these spiracles open anteriorly, the reverse of the thoracic spiracle, and those of the first instar differ from those of the other two instars as mentioned above (page 624).

The ventral side of each abdominal segment (Fig. 49) except the tenth bears an irregular transverse row of setae and a few other setae laterally. The intra-segmental folds of the integument are shown by dotted lines in the figure. On the ventrum of the ninth segment there is a conspicuous setiferous protuberance laterally. The ventral side of the tenth segment bears two nearly parallel rows of very short, heavy, spine-like, recumbent setae which point mesad. The number of these setae varies and is not usually the same in both rows on one individual. There may be as few as ten and as many as sixteen in either row, and there may be as many as three more in one row than in the other. The number found is usually between eleven and fourteen. There is frequently a slight tendency for these rows to diverge anteriorly. This structure is frequently used in identifying Scarabaeid larvae, since it is relatively constant in one species and varies much among species but it alone cannot be relied on, since both *Phyllopertha horticola* (see Rittershaus 1927) and *Pachystethus lucicola* (see Böving 1921) have a similar arrangement and may have the same number of setae in some cases. In *Anomala orientalis* the distance between the border of the anal opening and the posterior end of the two rows is about half the length of the rows. There are several strap-like setae with hooked ends on each side of the central rows and between the anal opening and the posterior ends of the rows. The anal opening is bordering by fine setae similar to those found on the dorsum and is crescentic in shape.

THE PREPUPA (PLATE XIX)

The prepupa does not represent a morphologically distinct stage in the development of this insect but is merely a quiescent period which terminates the third larval instar. The larva is in the third instar but is not active. The legs are folded at the coxa-trochanter joint and are useless. The intestine is evacuated and the body of the larva appears creamy white in color.

THE PUPA (FIG. 51 AND PLATE XIX)

The pupa (Fig. 51) is about 10 mm. long, about 5 mm. in greatest diameter, and light brown in color. There are many fine setae on the legs, antennae, and dorsal surface of the body, and the caudal end of the abdomen bears a thick fringe of setae. The entire body is covered with a very fine pubescence.

On the ventral side all the mouth parts and the thoracic appendages are distinct. The epicranial suture is evanescent, and the vertex and frons are fused together. The eyes are partly concealed by the bases of the antennae. The antennae border the mouth parts laterally and are indistinctly divided into three lobes. The clypeus is trapezoidal in shape with a slightly sinuate posterior margin (fronto-clypeal suture). The labrum is asymmetrical, being slightly larger on the left side than on the right, and slightly inflexed at the tip. The mandibles are crescentic and border the clypeus and labrum laterally, being partly concealed by them. The maxillae project from beneath the mandibles and each consists of one lobe to which is attached laterally an indistinctly segmented palpus. The labial palpi touch each other at their tips and lie transversely across the base of the conical labium. Figure 51 is a diagram of a young pupa. Near the close of the pupal period the mouth parts become more inflexed and differ slightly in appearance from the diagram. The lateral areas of the pronotum border the eyes and antennae. The thoracic legs are folded so that medially the tip of the coxa and the base of the femur are visible beneath the tibia and tarsus. On the prothoracic legs there is a short spur at the outer apical angle of the tibia, and on the mesothoracic and metathoracic legs there are two spurs at the inner apical angle of the tibia. The former represents the tibial spur of the adult, whereas the latter represent heavy fixed spines. The anterior tarsi have the segments very slightly indicated, but the segmental divisions are a little more clearly shown on the mesothoracic tarsi, and they are quite distinct on the metathoracic tarsi. The tips of the anterior legs extend well into the posterior half of the metathoracic sternum, and the tips of the mesothoracic legs extend to about the middle of the third abdominal segment. The metathoracic legs extend to the ninth abdominal segment in the male and to the eighth in the female. The wings lie between the second and third pairs of legs. The mesothoracic wings cover those of the metathorax except at the tips and along the medial margin. The anterior wings are very faintly ridged. Between the first and second coxae there is a very small part of the mesothoracic sternum visible, but posterior to the second coxae the visible part of the metathoracic sternum is quite large.

The ventral side of the abdomen differs in the two sexes. The first eight visible segments are similar in each sex, but posterior to the eighth visible (the ninth true abdominal segment) are the anlagen of the adult genitalia in the male. The first abdominal segment is not visible ventrally, and the second is almost entirely covered by the thoracic appendages. Segments three to nine are distinct. Three to six inclusive are about equal in length, but seven and eight are wider than those preceding, and the ninth is a very narrow band about one-third (female) to one-fourth (male) the width of the eighth. Laterally there is a pleural fold along the length of the abdomen which is very prominent on segment eight and posteriorly. Posterior to the ninth segment of the male there are two lobes, the anlagen of the parameres (lateral lobes), and posterior to this the anlage of the penis. This latter is partly divided by a suture representing the future ejaculatory duct. The abdomen of the male is more slender than that of the female. The external genital opening lies in segment nine. The visible area posterior to the genitalia of the male is the dorsal part of segment ten.

Dorsally the two sexes are alike. The pronotum is similar in shape to that of the adult. The mesonotum is about equal in width to the metanotum and about one-half again as broad as long. The metanotum is about twice as broad as long and about half as long as the pronotum. The suture separating the meso- and metanotum is convex posteriorly. The wings of each segment are indistinguishably fused with the notum. There are dorsally visible nine abdominal segments. Close to the middle of each of the division lines separating the first seven segments from each other is a pair of incised pockets whose edges are slightly curved and heavily chitinized. The eighth segment is convex at the posterior margin, being wider at the middle, and

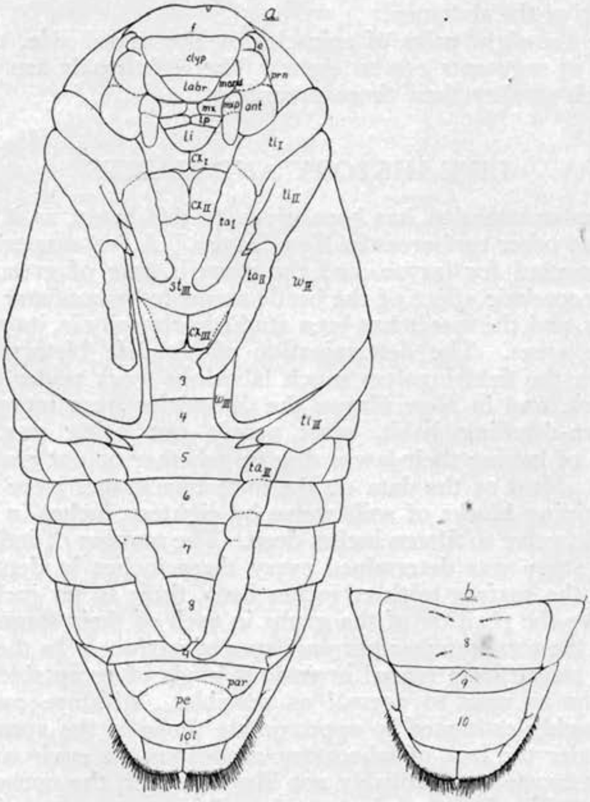

FIG. 51. a. Male pupa, ventral aspect. b. Tip of abdomen of female pupa, ventral aspect. *ant*, antenna; *clyp*, clypeus; *cx*, coxa; *e*, eye; *f*, frons; *labr*, labrum; *li*, labium; *lp*, labial palpus; *mand*, mandible; *mx*, maxilla; *mxp*, maxillary palpus; *par*, paramere; *pen.* penis; *prn*, pronotum; *st*, sternum; *ta*, tarsus; *ti*, tibia; *w*, wing. "*t*" signifies dorsal. The Roman numerals indicate the thoracic segments and the Arabic the abdominal.

represents the pygidium of the adult. The ninth segment extends to the tip of the abdomen. The anus is concealed by the anlage of the penis in the male and the tenth segment is probably represented by the membranous integument surrounding it. In the female the broad area on the ventral side posterior to the ninth sternite is the tenth, and the tenth tergite is on the ventral side of the tip of the abdomen.

There are eight pairs of spiracles on the dorsal side, one pair on each of segments one to eight. The eighth pair are reduced and much smaller than those preceding.

LIFE HISTORY AND HABITS

Particular attention has been given to this insect as it lives in lawns and other turf areas in New Haven. A few nurseries have been inspected for larvae, and the same is true of greenhouses, but the economic effect of the beetle seems to be confined entirely to lawns, and the insect has been studied primarily in its relations to these areas. The determination of the life history of soil insects in the field involves much laborious work under the best conditions, and in New Haven the difficulties were increased by this lawn-dwelling habit, most people not being particularly desirous of having their lawns dug up whether or not grubs were present. Most of the data on the immature stages were secured by examining blocks of soil twelve by eighteen inches in surface area and twelve to fifteen inches deep. The number of individuals of each stage was determined every three inches in depth; that is, from the surface to three inches deep, three to six inches, etc. This gave the position of the grubs in each of their stages in the soil and the total number per unit area of surface. In the insectary, the larvae were reared in various kinds of receptables under conditions as near to normal as possible. Moisture conditions were roughly estimated to approximate those of the normal soil. Even under the best of laboratory conditions the environment of growing larvae was probably not identical with the normal environment. The lengths of stages here given are those of insectary-reared individuals except where otherwise stated. These periods checked well with field observations except that the lengths of the larval instars in the insectary were somewhat longer than in the field. The data on the adults were secured both from captive beetles and from field observations. A brief summary of the life cycle in Hawaii has been published by Muir (1912) and in Connecticut by Friend (1927).

The adults emerge from the pupal stage in the ground during the latter part of June, and throughout the months of July and August. They usually remain in the soil one or more days before coming to the surface, and a few specimens have been observed to remain in the soil seven days, but these cases may represent a much longer time than the average in the field. Pupation occurs at three to nine inches below the surface of the ground, and the adults remain in the pupal chambers until the chitin hardens, which takes about one day. In 1926 the first adults were found in the field June 25, in 1927, June 29, and in 1928, June 26. The last were found August 28, 1926, and September 9, 1927. No field scouting for adults was carried on the latter part of the summer in 1928. In the insectary where conditions of temperature were essentially the same as out-doors, we secured adults as early as June 15 in 1927. During 1926 they were most abundant from July 13 to July 24, and during 1927 from July 11 to July 13. They live from two to three weeks.

Our observations indicate both diurnal and nocturnal activity. During the day the beetles are in flight during both morning and afternoon and are frequently found in flowers, where they feed on the petals, although not extensively. At night they are sometimes found around lights crawling on the ground, window frames, etc. They are not very active when compared with our native May beetles or with the Japanese beetle. Flight is short, often only a few feet, and much of the time is spent in the ground where they are often found in burrows an inch or half an inch deep (Plate XX). No precise data are available on the effect of humidity and temperature on the activities of the adults. In 1927, a record was kept of the sex of 693 adults collected between July 13 and September 9, when the last adult was found. These beetles, with very few exceptions, were picked up on flowers and foliage or on the surface of lawns; 590 were females and 103 were males. The significance of this is not quite clear, for between July 19 and September 3 there emerged from our insectary tiles 176 males and 137 females, near enough to an equality of sexes to cause no comment. The scouts were instructed to examine flowers carefully, and if the females feed more than the males, the preponderance of the former is explained. Muir noticed the same preponderance of females collected on flowers in Hawaii.

The adults feed very little, and it is possible that what they eat may be consumed for the sake of its moisture content. They are frequently found in rose blossoms, hollyhocks, phlox, dahlias, etc., and we have fed them on roses in the insectary, but the amount of food consumed is rarely enough to injure the flower seriously. We fed adults in captivity on pieces of ripe apple. They will not eat an apple the skin of which is entire, but if the flesh is exposed they eat out a cavity about large enough to hold the body. They will also burrow into a wet sponge and bury their heads in wet cotton. Water seems to be the substance sought in this case. If apple pulp is placed in a receptacle where it cannot be reached except by flight they are not attracted to it and we have never found them on fruit in the field. In the adult stage the feeding habits of this insect are of no economic importance.

A few specimens have been found mating in the field, but most of the observations on the mating habits have been made on adults in captivity. They are both polygamous and polyandrous, mating indiscriminately. One male will mate with more than one female, and one female will mate with more than one male on the same day. No attempt has been made to determine the limit in this direction, but in breeding work in the out-door insectary pairs could be mated at almost any time. In some instances one male has mated with two females successively with no appreciable interval. The reverse has also occurred, and one pair may mate twice the same day. The duration of the act of copulation varies from fifteen minutes to two hours. Mating below the surface of the ground has never been observed in the field or laboratory, and we do not believe it occurs normally.

The intervals between emergence from pupal skin and mating, and between mating and oviposition show much variation. The female may mate and oviposit within one day of the time of shedding the pupal skin, but usually a longer time elapses in captivity, at least. Although as much as five days may elapse between mating and oviposition in captivity, under natural conditions the duration of time may be much less. Whether one mating or more is required for oviposition of the normal number of eggs has not been ascertained. Some females seem to be stimulated to renewed egg-laying activity by a second mating, but oviposition in the laboratory is so irregular that no conclusion has been drawn as regards this matter.

The period of oviposition is from four to twenty days, usually about one week. During this time eggs are laid during both day and night in small groups placed loosely in the ground usually at a depth of between three and nine inches. Six 1928 diggings taken from field records show that of 437 eggs found, 78 per cent. were between three and nine inches below the surface of the soil, 12 per cent. were in the upper three inches of soil, and 10 per cent. were between nine and twelve inches below the surface. Of those found outside the three to nine inch layer, most were close to the three-inch or nine-inch level. Our experience has been that more eggs are found between four and eight inches below the surface in the field than at all other levels. From one to twelve eggs per day are laid in captivity, the largest total number from one beetle being 39, laid over a period of seven days. The average is much less. (We have secured an average of 26.4 eggs per female from nine individuals). The first eggs were found in the field in 1926 on July 19, and the last on September 10. In 1927, the first egg was found on July 3, and the last in September (day not recorded). In 1928, the first eggs were found July 3. The adults will oviposit in ground covered with sod or bare. No search has been made for eggs in bare ground more than a few feet from sod, but they are frequently found in gardens in yards. In tests made to determine the preference of adults for turf or bare ground three trials were made. A box having inside dimensions 10″ x 20″ contained earth covered with sod in one half, and earth without sod in the other, the depth of each half being five inches. In the first trial 25 pairs of adults were placed in each half, a thin partition preventing the two lots from intermingling, and left for four days. The side with sod contained 17 eggs, and the side without sod, 42 eggs. The sod, which was cut from a lawn seeded to red top grass in April and maintained in excellent condition by watering until used in July and August, was not compressed when placed in the frame. This was repeated with five pairs of adults on each side over a period of five days. Six eggs were found on the side containing sod and three on the other. In the third trial nine pairs of adults were placed on each side and the partition was removed above ground, permitting free access to both sides by all 18 pairs for three days. The partition was kept intact below the surface to prevent passage from one side to the other under ground. After three days the side with sod contained 26 eggs, and the side without sod, 22. Of the 116 eggs laid in all trials, 49 were laid in the side containing sod and 67 in the side without sod. The preference, if any, was slight. In breeding these insects in captivity, the adults are confined in small (four-inch to six-inch) flower pots or in jelly jars which contain earth without any living organic matter, and they oviposit very readily, although perhaps not to the extent attained in a more nearly normal environment. The infested area in New Haven is a suburban residential district where the properties have fair-sized lawns, and hence it is impossible to tell from field observations to what extent cultivated land would be infested in this region.

The egg is small and oval when laid, but it soon swells to a more nearly spherical shape and increases much in size. Full size is attained after about two weeks at 24° C. (75° F.) in moist soil. The duration of the egg stage at the same temperature and under the same conditions is 17.3 ± 0.1 days (53 eggs). Under out-door conditions of air temperature and in moist soil the duration of the egg stage for 121 eggs laid between July 14 and August 19 in 1927 was 24.7 ± 0.2 days. In 1926, the average was 27.8 ± 0.6 days for 63 eggs held under similar conditions out-doors and laid between August 2 and September 2. The soil temperature in Westville, New Haven, at a depth of six inches fluctuated during August 1926 and 1927 between the extremes of 61° and

84° F. However, the eggs on which data are given were kept in bottles full of earth in the insectary at air temperature, and the mean is much below 75° F. during July, August, and September, being 71.7° F., 71.3° F., and 62.8° F., respectively, in 1926, and 72.4° F., 66.9° F., and 65° F., respectively, in 1927 (U. S. Weather Bureau figures). Moisture seems absolutely essential to the development of the embryo. Lack of moisture retards development, and an exposure to air-dry conditions for the first ten days is fatal. Submergence in water also retards development, but eggs can survive at least seven days' submergence immediately after being laid.

Just before hatching, the brown tips of the mandibles are visible through the egg shell. Some of the brown setae are also visible through the shell, but the body of the larva is white on hatching. The egg-bursters on the metathorax (Fig. 50) aid the hatching process by pressing against the shell from the inside. These do not act as knives, for the shell breaks in what might be called a frontal plane, but simply furnish points for the application of pressure. The function of these and their morphology are very well described by Rittershaus (1925 and 1927). They are cast off at the first molt. The first newly-hatched larvae were found in the field on August 12, 1926, July 29, 1927, and July 17, 1928. First instar larvae occur during the remainder of the summer and fall and a certain per cent. hibernate.

As soon as they break from the egg shell, the young larvae move up to a point near the surface of the soil to feed on the grass roots and dead organic matter found there. This movement may be affected somewhat by the amount of organic matter in the soil, for if organic matter is plentiful, the larvae tend to migrate less. In normal sandy loam occurring just under the sod as found in New Haven, this tendency to move up is quite manifest. If eggs are placed at the bottom of tubes filled with soil, the larvae move up after hatching, but if the eggs are placed at the top of the tube (one centimeter below the surface of the soil) the larvae stay there. Moisture may possibly be an important factor in the movement of the larvae, for a very dry soil is fatal to them, and excess dryness of the top layers might cause them to go down or remain down more deeply.

Although under normal conditions the young larvae apparently feed on both grass roots and dead organic matter, they can maintain themselves and develop on the latter alone. It is not inferred that the dead organic matter is a sterile medium, for bacteria and fungi are present and may be a very important factor in the nutrition of the larvae.

They will live and grow on soil containing much decayed sod, but in this case the rate of development is not so rapid as when the food supply consists of normal growing turf nor do the larvae grow to normal size. Aside from direct laboratory experimentation to determine this point, good evidence is given by the migration experiments that development is much more rapid in sod than in sandy loam. Of the 200 first instar larvae placed in the frame containing sod, 141 survived, 84 being in the second instar and 57 being in the first after 21-23 days. Of the 200 placed in the frame without sod, 95 survived, 35 being in the second instar and 60 in the first. These 400 larvae were all from miscellaneous insectary-reared material and were not selected for age. The average larval age was the same, as the lot was mixed. In the migration experiment with the small frame, 28 larvae survived in the frame without sod, and only eight of these had reached the second instar after 28-29 days. In the frame with sod, 36 larvae survived and 27 had reached the second instar. It is interesting to note that first instar larvae in the summer feeding season can survive a fairly long period of time and develop somewhat in soil no richer in organic matter than garden sandy loam.

The young larvae migrate laterally to some extent, depending much on the nature of the soil. If sod is present, migration is less than when the soil contains no sod. Figure 52 shows the distribution of larvae when living sod is present or absent. The frames used were two feet square inside, six inches deep, and with 20-mesh copper screen on the bottom. Each frame was filled to within one inch of the top and set in the ground out-doors. One frame contained sandy loam with no sod, and the other contained in the center a circular piece of sod one foot in diameter. The larvae (first instar) were placed with a little earth in a jelly jar having a two and a half-inch mouth, and this was inverted over the exact center of the frame and the larvae allowed to dig in. After 21 to 23 days (August 16 to September 6 to 8) the soil was removed in concentric rings one inch in thickness beginning at the periphery. All larvae found beyond twelve inches from the center were in the corners, and all larvae found in the first four inches from the center are given in one total. Two hundred larvae were placed in each frame. The method of handling accounts for much of the mortality, and the figures represent the survivors. In the frame with no sod, 95 larvae survived, and in the frame with sod, 141 larvae survived. In this latter frame 111 (79 per cent) of the larvae were within six inches of the center, (that is, in the sod itself) and only ten (seven per cent) were more than ten inches from the center, whereas in the frame containing no sod, 11 (11.6 per cent) were within six inches of the center, and 40 (41.9 per cent) were more than ten inches from the center. The presence of living sod very apparently influences migration in the soil, and this is substantiated by similar tests made with third instar larvae as given on page 637 and in Figure 53.

In two similar frames one foot square inside and filled three inches deep, one frame containing no sod and one being entirely turf, the distribution of the larvae show a similar tendency. One hundred larvae were placed in each frame on August 17, 1927, and an examination was made as before on September 14 and 15. Of the 28 survivors in the frame with no sod, 20 (71 per cent) were over five inches from the center, and in the frame with sod 20 (55 per cent) of the 36 survivors were over five inches from the center. The low survival rate in these last frames was probably due to the method of handling and to drying out. If concentrated in a small space, the larvae bite each other with frequently fatal results from infection.

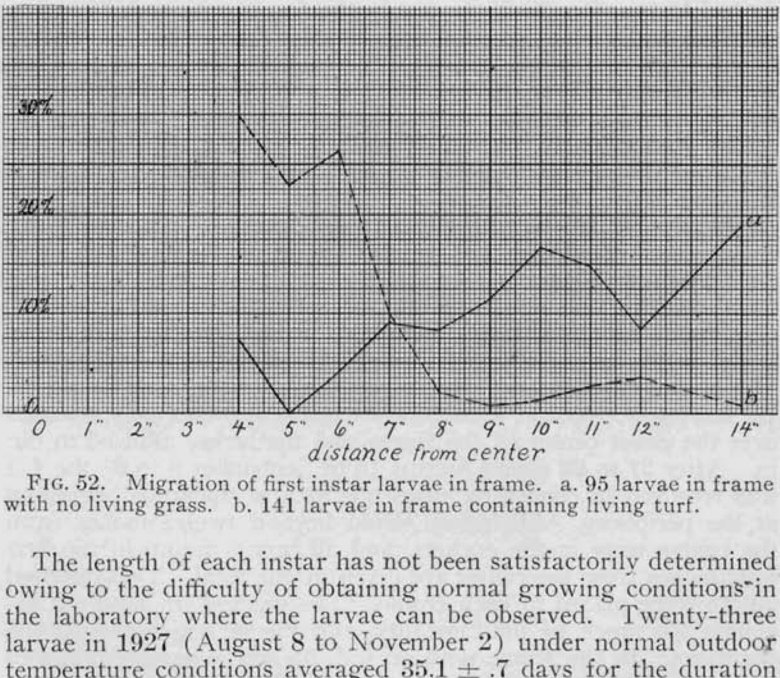

FIG. 52. Migration of first instar larvae in frame. a. 95 larvae in frame with no living grass. b. 141 larvae in frame containing living turf.

The length of each instar has not been satisfactorily determined owing to the difficulty of obtaining normal growing conditions in the laboratory where the larvae can be observed. Twenty-three larvae in 1927 (August 8 to November 2) under normal outdoor temperature conditions averaged 35.1 ± .7 days for the duration of the first instar. When held at a temperature of 23°—25°C., the first instar is completed in less than 30 days. In both cases larvae were kept in living sod. Under the same conditions larvae fed on soil rich in dead organic matter (decayed sod) take about one-third again as long (about 40 days). The second instar apparently takes about as long as the first, and the majority of larvae hibernate in the third instar. The first week in September the second instar larvae become common and injury to lawns becomes noticeable at this time. By the last of September most of the larvae are in the third instar. The second and third instars feed as does the first, and it is the activity of these later stages which injures the grass so severely (Plate XX). In 1928, the first injury to grass was noted August 17, the larvae being then in the second instar, and by September 15 the injury to lawns was very severe. The roots are cut off close to the crown, and in heavy infestations the dead grass can be rolled off the surface of the soil with ease.

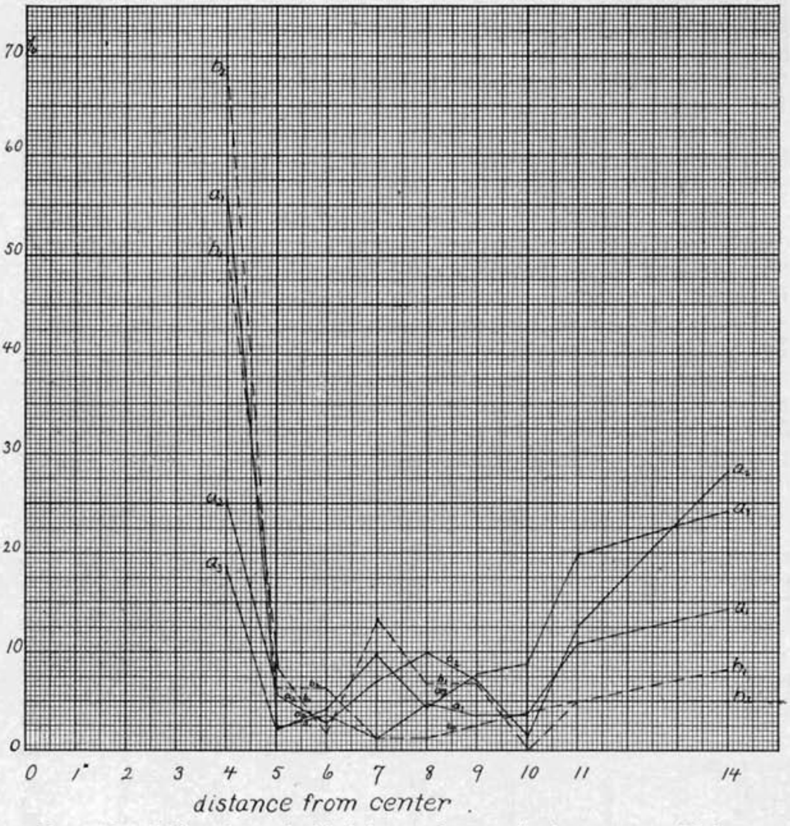

FIG. 53. Migration of third instar larvae in frame. a_1, 84 larvae; a_2, 71 larvae; a_3, 91 larvae—all in frame with no living grass. b_1, 60 larvae; b_2, 80 larvae—all in frame containing living turf.

The larvae are found in the characteristic position just below the surface of the soil. The third instar shows more lateral migration in the absence of grass roots than when in sod, as curves in Figure 53 indicate. One hundred larvae were used in each trial and the figures represent the survivors. The larvae remained in the frames as follows: a_1, Sept. 21-24; a_2, Sept. 23-28; a_3, Sept. 28-30; b_1, Sept. 21-28; b_2, Sept. 29-30. The procedure was the same as with larvae of the first instar (page 635). The difference is not so great as with the larvae of the first instar, but the time was much shorter in every case. Lot a_1 had a higher per cent within the first four inches of the center than b_1, but the larvae were in the frame in the former case three days as against seven days in the latter, and even with this greater length of time the dispersion beyond four inches shows a greater migration when no grass roots are present. The tendency to move farther laterally in the absence of grass may be a factor of some importance in controlling the larvae when arsenate is used in the soil. Although a search for food may be the primary cause of this migration, variations in the temperature and in the moisture content of the soil may have some effect. Grass cover on soil alters both temperature and moisture content when compared with a denuded area.

About the middle of October the larvae begin to move more deeply into the soil to hibernate, and by the time the ground freezes they are well below the surface. Hibernation occurs at a depth of from ten to fifteen inches usually, although the character of the soil seems to be a factor which influences this to a certain extent. In lighter and more easily penetrated soils the tendency is to go more deeply. Most of the larvae are in the third instar when hibernation occurs, but some are in the second and first instars. Figure 54 shows graphically the percentage of different stages found in the field as given in Table 6. In Figure 55 is shown the rate of

TABLE 6—SEASONAL OCCURRENCE OF EGGS, LARVAE AND PUPAE

April 21-30	Eggs	1st instar	2nd instar	3rd instar	Prepupae	Pupae	Total
4-25-28	0	1	36	242	0	0	279
4-26-26	0	5	0	49	0	0	54
4-26-28	0	0	0	34	0	0	34
4-29-27	0	0	7	20	0	0	27
	0	6 2%	43 11%	345 87%	0	0	394
May 1-10							
5-2-27	0	0	8	7	0	0	15
5-4-27	0	0	4	55	0	0	59
	0	0	12 16%	62 84%	0	0	74
May 11-20							
5-11-28	0	0	14	93	0	0	107
5-12-27	0	0	4	0	0	0	4
5-17-28	0	0	0	33	0	0	33
	0	0	18 13%	126 87%	0	0	144
May 21-30							
5-24-28	0	0	3 6%	45 94%	0	0	48
May 31-June 9							
6-4-28	0	2 3%	13 22%	40 70%	3 5%	0	58
June 10-19							
6-7-28	0	0	1	11	11	0	23
6-13-28	0	0	19	13	13	4	49
6-15-28	0	0	2	9	37	6	54
6-16-28	0	0	3	11	12	4	30
6-17-26	0	0	0	3	31	52	86
6-18-26	0	0	0	8	2	7	17
6-18-28	0	0	5	5	5	25	40
	0	0	30 10%	60 20%	111 37%	98 33%	299

TABLE 6—SEASONAL OCCURRENCE OF EGGS, LARVAE AND PUPAE —*Continued*

	Eggs	1st instar	2nd instar	3d instar	Prepupae	Pupae	Total
June 20-29							
6-25-26	0	0	0	20	12	8	40
6-25-28	0	0	10	9	0	8	27
6-26-28	0	0	2	3	3	35	43
6-27-28	0	0	6	11	2	27	46
6-29-26	0	0	0	5	9	19	33
	0	0	18 10%	48 25%	26 14%	97 51%	189
June 30-July 9							
6-30-26	0	0	0	11	4	15	30
7-2-28	0	0	0	1	1	0	2
7-3-28	2	0	1	3	0	12	18
7-5-28	60	0	0	4	0	3	67
	62 53%	0	1 1%	19 16%	5 4%	30 26%	117
July 10-19							
7-12-28	45	0	0	2	0	0	47
7-17-28	263	40	0	3	0	0	306
7-19-26	12	0	4	1	1	0	18
	320 86%	40 11%	4 1%	6 2%	1	0	371
July 20-29							
7-20-28	11	4	10	0	1	0	26
7-26-28	19	211	0	3	0	0	233
	30 12%	215 83%	10 4%	3 1%	1	0	259
July 30-Aug. 8							
7-30-26	50	1	0	3	2	0	56
7-30-28	0	92	0	6	0	0	98
7-31-26	15	0	0	0	0	2	17
8-2-28	0	165	0	2	0	0	167
8-4-26	10	0	0	1	0	1	12
8-6-28	2	0	0	0	0	0	2
	77 22%	258 73%	0	12 3%	2 1%	3 1%	352
Aug. 9-18							
8-15-28	5	120	118	9	0	0	252
8-16-28	0	32	3	5	0	1	41
8-17-28	0	42	86	13	1	0	142
	5 1%	194 45%	207 48%	27 6%	1	1	435
Aug. 19-29							
8-20-28	0	22 11%	168 83%	13 6%	0	0	203
Aug. 29–Sept. 7							
8-30-28	0	2 3%	53 83%	8 12%	1 2%	0	64
Sept. 8-17							
9-8-28	0	6	76	1	0	0	83
9-9-27	0	0	163	51	0	0	214
9-10-27	0	25	2	0	0	0	27
9-11-28	0	16	141	37	2	0	196
9-12-27	0	14	137	38	0	0	189
9-14-27	1	0	1	0	0	0	2
9-15-27	1	2	0	0	0	0	3
9-16-27	0	1	16	3	0	0	20
9-17-27	1	15	19	6	0	0	41
9-17-28	0	0	30	135	0	0	165
	3	79 8%	585 62%	271 29%	2	0	940
Sept. 18-27							
9-19-27	0	17	88	67	0	0	172
9-20-27	0	9	46	93	0	0	148
9-21-27	0	0	0	73	0	0	73
9-22-27	0	25	53	281	0	0	359
9-23-27	0	13	100	87	0	0	200
9-24-27	0	2	96	95	0	0	193
9-26-27	0	43	118	247	0	0	408
9-27-26	0	1	4	1	0	0	6
	0	110 7%	505 32%	944 61%	0	0	1559

TABLE 6—SEASONAL OCCURRENCE OF EGGS, LARVAE AND PUPAE —*Concluded*

	Eggs	1st instar		2nd instar		3rd instar		Prepupae		Pupae	Total
Sept. 28-Oct. 7											
9-28-28......	0	1		9		70		0		0	80
9-29-26......	0	0		0		72		0		0	72
10-1-26......	0	0		15		4		0		0	19
10-2-28......	0	4		40		139		3		0	86
10-4-26......	0	1		7		27		0		0	35
10-5-26......	0	0		3		6		0		0	9
	0	6	1%	74	18%	318	80%	3	1%	0	401
Oct. 8-17											
10-8-26......	0	2		14		16		0		0	32
10-8-28......	0	0		3		46		0		0	49
10-9-28......	0	1		16		132		0		0	149
	0	3	1%	33	14%	194	84%	0		0	230
Oct. 18-27											
10-18-28.....	0	2		1		94		0		0	97
10-20-27.....	0	11		22		219		0		0	252
10-21-27.....	0	0		15		199		0		0	214
10-22-27.....	0	0		0		38		0		0	38
10-24-27.....	0	17		37		45		0		0	99
10-25-27.....	0	11		43		176		0		0	230
10-26-27.....	0	10		36		204		0		0	250
10-27-27.....	0	5		15		87		0		0	107
	0	56	4%	169	13%	1062	83%	0		0	1287
Oct. 28-Nov. 6											
10-28-27.....	0	2		21		87		0		0	110
10-29-27.....	0	0		13		74		0		0	87
10-31-27.....	0	0		7		39		0		0	46
11-1-27......	0	0		4		44		0		0	48
	0	2	1%	45	15%	244	84%	0		0	291
Nov. 7-16											
11-7-27......	0	2		4		66		0		0	72
11-10-27.....	0	0		4		67		0		0	71
11-15-27.....	0	4		110		206		0		0	320
	0	6	1%	118	24%	339	73%	0		0	463
Nov. 17-26											
Nov. 27-Dec. 6											
11-30-27.....	0	5	2%	98	33%	194	65%	0		0	297
Dec. 7-16											
12-14-27.....	0	0		18	24%	58	76%	0		0	76

descent into the soil according to Table 7. During the month of October, 1927, the soil temperature in Westville, New Haven, at a depth of three inches fluctuated betwen 78° F. and 39° F, and in November between 58° and 31°, and the descent in the soil occurs in these two months. This movement down into the soil is not necessary for survival of the low temperatures, although it always occurs as winter approaches. In October of 1926, 24 larvae were buried at each of the depths given in Table 8 and allowed to remain until April 1, 1927. The larvae were placed in salve tins 2⅜ inches in diameter and 1⅝ inches deep, two larvae in each tin, and the tins filled with earth. In the cover and bottom of each tin a one-inch hole was cut and copper screen soldered over the openings. The depth was measured from the surface of the soil to the center of the container. Twenty-four larvae were placed at each depth. The differences in survival at

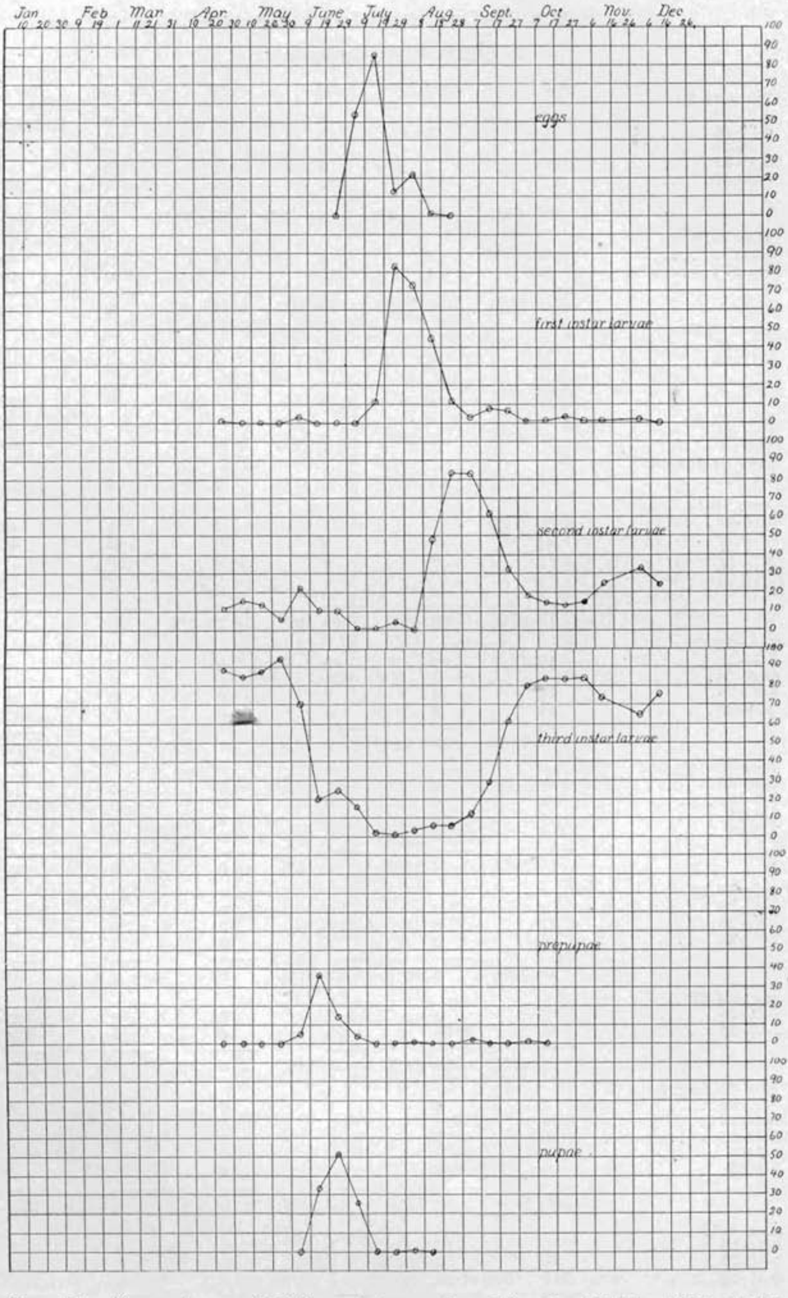

FIG. 54. Percentages of different stages found in the field in 1926, 1927 and 1928.

Table 7—Depth of Larvae in Soil

(Including prepupae)

	0–3"		3–6"		6–9"		9–12"		12–15"	Total
April 21-30										
4-25-28........	237		31		8		3		0	279
4-26-26........	11		17		15		11		0	54
4-26-28........	33		1		0		0		0	34
4-29-27........	9		13		3		2		0	27
4-30-27........	117		17		22		51		0	207
	407	68%	79	13%	48	8%	67	11%	0	601
May 1-10										
5-2-27.........	50		23		9		4		0	86
5-4-27.........	62		14		17		7		0	100
	112	60%	37	20%	26	14%	11	6%	0	186
May 11-20										
5-11-28........	95		5		4		3		0	107
5-17-28........	28		2		2		1		0	33
	123	88%	7	5%	6	4%	4	3%	0	140
May 21-30										
5-24-28........	41	85%	5	10%	2	4%	0		0	48
May 31-June 9										
6-4-28.........	47	58%	23	28%	9	11%	2	2%	0	81
June 10-19										
6-13-28........	30		9		7		2		0	48
6-15-28........	21		20		0		0		0	41
6-16-28........	15		8		3		0		0	26
6-17-26........	3		18		1		0		0	22
6-18-26........	3		11		3		0		0	17
	72	47%	66	43%	14	10%	2	1%	0	154
June 20-29										
6-25-28........	17		2		0		0		0	19
6-26-28........	5		1		1		1		0	8
6-27-28........	14		4		1		0		0	19
6-29-26........	11		6		0		0		0	17
	47	75%	13	21%	2	3%	1	2%	0	63
June 30-July 9										
6-30-26........	7		3		1		0		0	11
7-2-28.........	2		0		0		0		0	2
7-3-28.........	4		0		0		0		0	4
7-5-28.........	2		0		0		0		0	2
	15	80%	3	16%	1	5%	0		0	19
July 10-19										
7-12-28........	2		0		0		0		0	2
7-17-28........	21		8		14		0		0	43
7-19-26........	4		0		2		0		0	6
	27	53%	8	16%	16	31%	0		0	51
July 20-29										
7-20-28........	10		2		3		0		0	15
7-26-28........	82		98		28		6		0	214
	92	40%	100	44%	31	14%	6	3%	0	229
July 30-Aug. 8										
7-30-26........	1		4		1		0		0	6
7-31-28........	71		18		9		0		0	98
7-31-26........	0		2		0		0		0	2
8-2-28.........	158		9		0		0		0	167
8-4-26.........	0		2		0		0		0	2
	230	84%	35	13%	10	4%	0		0	275
Aug. 9-18										
8-15-28........	236		10		1		0		0	247
8-16-28........	40		0		0		0		0	40
8-17-28........	111		21		7		3		0	142
	387	90%	31	7%	8	2%	3	1%	0	429

TABLE 7—DEPTH OF LARVAE IN SOIL

(Including prepupae)—*Concluded*

	0–3"		3–6"		6–9"		9–12"		12–15"		Total
Aug. 19-28											
8-20-28.......	145	71%	42	21%	16	8%	0		0		203
Aug. 29-Sept. 7											
8-30-28.......	62	96%	1	2%	1	2%	0		0		64
Sept. 8-17											
9-8-28........	83		0		0		0		0		83
9-9-27........	156		44		14		0		0		214
9-10-27.......	18		6		3		0		0		27
9-11-28.......	135		54		5		2		0		196
9-12-27.......	159		19		1		0		0		179
9-17-27.......	13		25		2		0		0		40
9-17-28.......	114		32		16		3		0		165
	678	75%	180	20%	41	4%	5	1%	0		904
Sept. 18-27											
9-19-27.......	107		50		12		2		0		171
9-20-27.......	124		8		2		0		0		134
9-21-27.......	230		64		35		0		0		329
9-22-27.......	172		7		1		0		0		180
9-23-27.......	169		12		7		0		0		188
9-24-27.......	154		18		2		0		0		174
9-26-27.......	365		33		9		0		0		407
9-27-26.......	6		0		0		0		0		6
	1327	84%	192	12%	68	4%	2		0		1589
Sept. 28-Oct. 7											
9-28-28.......	76		4		0		0		0		80
9-29-26.......	70		1		0		1		0		72
10-1-26.......	16		2		0		1		0		19
10-2-28.......	171		8		4		3		0		186
10-4-26.......	32		1		2		0		0		35
10-5-26.......	9		0		0		0		0		9
	374	93%	16	4%	6	2%	5	1%	0		401
Oct. 8-17											
10-8-26.......	26		3		2		1		0		32
10:8-28.......	35		13		1		0		0		49
10-9-28.......	137		8		3		1		0		149
	198	86%	24	10%	6	3%	2	1%	0		230
Oct. 18-27											
10-18-28......	57		14		13		13		0		97
10-20-27......	197		27		19		9		0		252
10-21-27......	176		28		6		2		0		212
10-22-27......	38		0		0		0		0		38
10-24-27......	74		13		5		3		0		95
10-25-27......	127		26		25		13		0		191
10-26-27......	124		35		43		34		0		236
10-27-27......	53		15		22		13		0		103
	846	69%	158	13%	133	11%	87	7%	0		1224
Oct. 28-Nov. 6											
10-28-27......	71		12		16		11		0		110
10-29-27......	12		26		30		17		2		87
10-31-27......	23		16		4		3		0		46
11-1-27.......	22		15		9		2		0		48
	128	44%	69	24%	59	20%	33	11%	2	1%	291
Nov. 7-16											
11-7-27.......	12		37		12		4		0		65
11-10-27......	4		18		36		13		0		71
11-15-27......	26		120		86		47		50		329
	42	9%	175	38%	134	29%	64	14%	50	11%	456
Nov. 17-26											
Nov. 27-Dec. 6											
11-30-27......	6	2%	82	27%	104	34%	79	26%	37	12%	307
Dec. 7-16											
12-14-27......	0		19	25%	12	16%	21	28%	24	32%	76

TABLE 8—SURVIVAL OF LARVAE OVER WINTER

Depth (in.)	Recovered alive	Per cent living
3	20	83
6	18	75
9	21	88
12	19	79
15	17	71

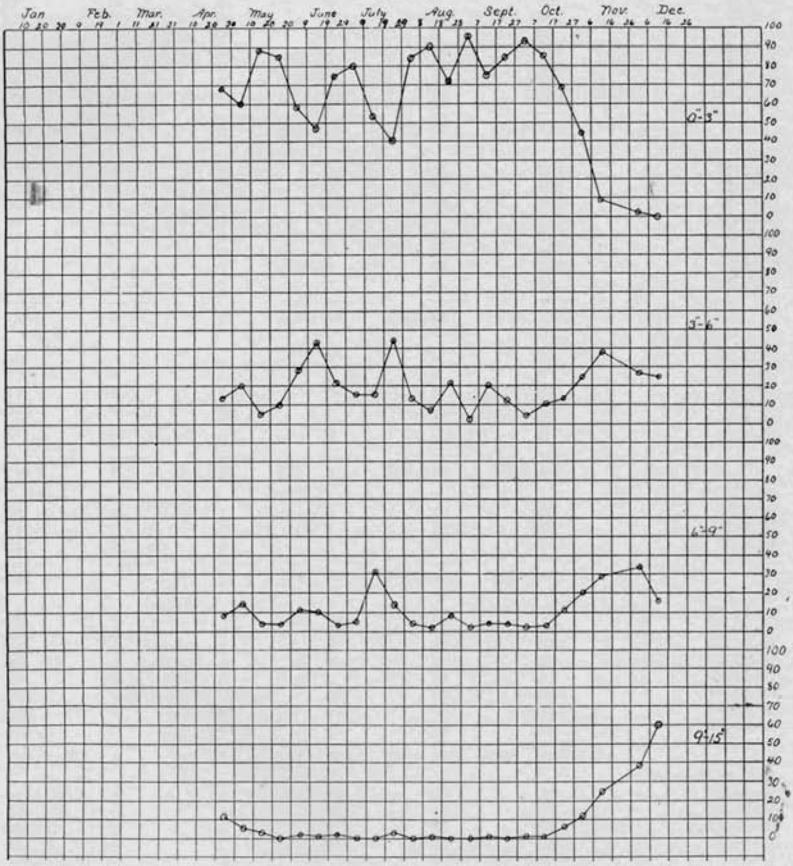

FIG. 55. Percentages of larvae (including prepupae) found at different depths in the soil in 1926, 1927 and 1928.

different depths cannot be considered significant with one experiment on a few animals, but it is quite apparent that the larvae can survive the winter in this locality with no great difficulty. If any larvae should attempt to hibernate within less than three inches of the surface, the mortality might be greater. A certain mortality is to be expected as a result of handling. The winter mortality under normal field conditions is negligible so far as our digging records indicate.

TABLE 9—SURVIVAL OF LARVAE OVER WINTER

	Instar	Oct. 5	Oct. 31	Nov. 7	Nov. 15	Nov. 30	Dec. 14	Apr. 25	May 17	May 24
0-3″	1st	..	0	1	0	0	0	0	0	0
	2d	..	0	0	1	1	0	10	0	2
	3d	..	23	11	1	0	0	227	28	39
3-6″	1st	..	0	1	0	1	0	0	0	0
	2d	..	6	3	5	5	5	26	0	0
	3d	..	10	33	47	12	14	14	2	5
6-9″	1st	..	0	0	0	0	0	0	0	0
	2d	..	1	0	2	2	2	0	0	1
	3d	..	3	12	7	14	10	1	2	1
9-12″	1st	..	0	0	0	0	0	0	0	0
	2d	..	0	1	2	3	6	0	0	0
	3d	..	3	3	15	13	15	0	1	0
12-15″	1st	..	0	0	0	0	0	0	0	0
	2d	..	0	0	1	0	5	0	0	0
	3d	..	0	0	1	4	19	0	0	0
Total No. of Larvae		63	46	65	82	55	76	278	33	48
Diggings		1	1	1	1	1	1	4	1	1
Per Digging		63	46	65	82	55	76	69.5	33	48

In Table 9 are given the results of the examination of a small infested area during the fall of 1927 and spring of 1928. The diggings were made very close together, a few inches separating them, and hence any lateral migration in the spring would disperse larvae into previously examined areas from which the larvae had been removed. This would thin the remaining infestation, which probably accounts for the drop in May. According to information received from the Japanese Beetle Laboratory of the Federal Bureau of Entomology there is a high mortality of the larvae of *Popillia japonica* in May, assigned by investigators to pathogenic bacteria, fungi, and other natural causes. This may also explain the decrease in the number of larvae of *Anomala orientalis* at this time. April 25 there were as many larvae per unit area as were present the previous November and December. There was no great apparent winter mortality under the conditions described.

With the advent of warm weather in the spring, the larvae come up close to the surface to feed, usually the latter part of April. Here they remain until the first part of June, when they go down a few inches to pupate. In the spring the grass is more vigorous than in the autumn, and the larvae feed less extensively, so the injury to the grass is less evident. A few larvae do no feeding whatsoever in the spring, and many can go through pupation without living grass roots for food, the dead organic matter in the soil being sufficient. Many of the second and first instar larvae coming from hibernation apparently do not pupate but go through the season as larvae and hibernate in the third instar the following winter. This seems to be the case with the majority of these immature larvae, and many have been carried through two seasons in the insectory. These represent but a small per cent of the total however, and most of the individuals complete development the first spring and summer after hibernation (Fig. 54).

The duration of the second and third instars depends much on environmental conditions. When larvae hatch late in the season the cool weather may delay development. Under similar conditions the first two instars take about the same length of time—one month. Under laboratory conditions and at an incubator temperature of 23° to 25° C. the larvae pass through two instars of growth in less than two months if kept in grass sod, and the entire larval period from hatching to pupation takes about 208.5 days (average of nine larvae which varied from 184 to 254 days).

Development depends on the nature of the food supply and on moisture as well as on temperature. Development takes place in soil containing decaying organic matter alone, and in the laboratory many larvae have been carried through to the prepupal stage on sod compost, although the duration of larval life was longer than that of larvae kept in living sod (at the time of writing these larvae are still in the prepupal stage, 222 days after hatching, the temperature being 23-25° C.* Lack of moisture is very quickly fatal and larvae cannot survive under air-dry conditions. When the soil is moist the first instar will live sometimes two weeks after hatching without any organic matter. In the laboratory newly hatched individuals in a few cases survived 11, 13 and 15 days in moist sand or mixed sand and brickyard clay. Under natural conditions the larvae could avoid excessive dryness by digging more deeply into the soil, but as long as the grass is alive they remain near the surface. In 1928, between May 1 and May 17 at New Haven, the precipitation was only .18 inches, and between May 12 and May 17 there was no rain whatsoever, yet on this latter date larvae were found feeding in the upper three inches of soil. Excessive moisture in the soil has little or no effect except possibly in flooded areas. We have no data on the latter condition, as none of the heavily infested area in New Haven is flooded at any season. Under artificially created conditions when the soil in which larvae were hibernating became so mucky that the cavities in the soil containing larvae were filled and the larvae tightly packed, death resulted in most cases. This condition could hardly

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*Two adults have since been secured ,one 274 and one 254 days after hatching.

be maintained in a natural environment, for the larvae were in metal containers where it was impossible for them to dig deeply into the soil, and water stood in the containers several weeks. It appears that as long as the larva can maintain freedom of movement in the soil it can survive.

The optimum conditions for larval development appear to be those that are attained in an open lawn exposed to the sun with a good cover of grass and with a fairly rich sandy loam. Any of the lawn grasses and clovers found in the infested area are eaten by the larvae. It is quite apparent that adverse conditions may be largely overcome. Prolonged rain, droughts, and cold weather have little apparent effect on the survival in this region. If no organic matter is present, it may be reached by lateral migration through the soil, for the newly-hatched larvae can survive days without it. Living roots are not absolutely necessary to development. The adults do not fly far in this climate and usually oviposit in an area favorable to development.

About the first of June the larvae dig into the ground to a depth of three to nine inches and undergo a prepupal quiescent stage. The intestine is emptied of its contents and the larva is yellowish-white in color. The abdomen is bent ventrally on itself in a very characteristic position (see Plate XIX), and the legs are folded up at the coxa-trochanter joint. Power of locomotion is lost, and the only movement is flexing and reflexing of the abdomen. By this movement a hollow space is formed in the soil, and in this space pupation occurs. The prepupal period varies somewhat and has been calculated as the period between loss of the power of locomotion and ecdysis. In 1926 this period was 6.9 ± .12 days in length (63 prepupae) and in 1927 the same period was 5.5 ± .24 days in length (20 prepupae). These observations in 1926 were made between June 19 and July 21, and in 1927 between July 9 and July 25. In the laboratory at 24° C. seven individuals had a prepupal stage varying from thirteen to six days and averaging 8.3 days. The depth to which the larvae will dig depends much on the nature of the soil. In the field most of the prepupae are found between three and nine inches below the surface, but they occur at a depth of 12 inches, and in tiles used for rearing, where the soil was relatively loose and easily penetrated, they went down 15 inches. When ready to pupate the larva splits the integument along the entire epicranial suture, the mid-dorsal line of the thorax, and the mid-dorsal line of abdominal segments 1-3.

Pupation occurs the last of June and the first of July in the majority of cases. In 1926 the first pupae were found in the field June 17, in 1927, June 15, and in 1928, June 13, and the last pupae were found in 1927 on August 19 and in 1928 on August 16. The pupal stage lasts about two weeks, 40 individuals having an average of 14.8 ± .75 days in 1926 (observations made between June 28 and July 25) and in 1927 14 individuals averaged 13.7 ± .12 days (observations made between July 14 and August 8). These are insectary records. In the laboratory at 24° C. seven individuals varied from 11 to 13 days and averaged 11.7 days. During the last two weeks in June the temperature of the soil in Westville, New Haven, fluctuated between 56° F. and 82° F. at six inches depth in 1926 and 1927. The pupa remains within the cast larval skin. Plate XIX shows the characteristic position.

As given here, the total life cycle occupies one year, and for most individuals this is true. Figure 54 gives the percentages of different stages (except the imago) found during the year in New Haven. This figure is drawn from Table 6, which gives the results of a large number of diggings made during 1926, 1927, and 1928. Figure 55 shows the depth at which the larvae are found during the year according to Table 7. If the average adult life prior to oviposition be considered four days (this represents the average time from emergence from the pupal stage to the middle of the period of oviposition), then the following table shows the duration of different stages for 1926 and 1927. These figures are for individuals reared in the insectary under conditions as close as possible to normal.

TABLE 10—LENGTH OF DIFFERENT STAGES AT NEW HAVEN.

	1926		1927	
Adult (to oviposition)..	4	days	4	days
Egg................	27.8	"	24.7	"
Larva (by difference)..	311.5	"	317.1	"
Prepupa............	6.9	"	5.5	"
Pupa...............	14.8	"	13.7	"

A small percentage of larvae hibernate in the first and second instars, and some of these apparently have a two-year life cycle. In the insectary we carried these through two years, and our observations indicate that this is the case in the field. This extension of the life cycle may be due to a relatively poor food supply, to low temperatures at a critical stage of development, to internal factors, or to a combination of these. A small percentage of larvae do very little, if any, spring feeding, and these are probably the two-year individuals. An examination of Figure 54 shows the peak of prepupal abundance between June 9 and June 19, of pupal between June 19 and 29, of eggs between July 9 and 19, of first instar larvae between July 19 and August 8, of larvae of the second instar between August 18 and September 7. It also shows that one to two per cent of the hibernating larvae are in the first instar and about twenty per cent in the second instar. Figure 55 gives the depth at which larvae are found during the year. The drop in per cent found in the upper three inches of soil in June is due to the prepupal stage and in July to the hatching of larvae from eggs and their being discovered before they came to the upper layer of soil. A comparison with Figure 54 makes this clear, as well as other facts in the life cycle. Figure 55 also shows the ascent and descent in the soil in the spring and fall. In making these charts the data for all three years have been combined, but the variations due to seasonal differences in these years have been largely eliminated by using the totals of ten-day periods in computing the percentages. All the necessary information may be found in the tables.

CONTROL

Natural Factors

There is at present in New Haven to the best of our knowledge, no one natural factor or group of such factors which will keep the numbers of this insect down to a harmless level. The effect of climate on the increase and spread of this insect is a matter on which little information is available. The low winter temperatures have no great effect. Hibernation occurs in the larval stages and the larvae go down into the soil to a depth of 10 to 15 inches. As has been previously noted (page 640) they can survive the winter even if as near the surface as three inches. The effect of natural environmental factors has been further discussed on pages 640 to 647 of this bulletin.

Starlings are very frequently seen feeding on larvae in heavily infested areas, but even where this feeding has been extensive, there are enough live larvae left in the soil to injure the grass.

The Federal Bureau of Entomology is at present introducing parasites of the Japanese and Asiatic beetles, and a lot of 290 *Tiphia popilliavora,* a wasp native to Japan, was released in Westville, September 6, 1928, by Mr. J. L. King of the Bureau. This wasp is known to parasitize the larvae of *A. orientalis,* but it is too early to state whether or not the parasite will establish itself here. In the Hawaiian Islands the beetle has been eliminated as an economic pest by the introduction of another wasp, *Scolia manilae,* but attempts to establish this in the United States have failed. It apparently cannot withstand the climate, for its native home is the Philippine Islands, and it is not active at normal summer temperatures in Connecticut according to information received from Mr. Loren B. Smith, of the Japanese Beetle Laboratory at Moorestown, New Jersey.

A small percentage of larvae are destroyed in Hawaii by bacterial and fungous (Metarrhizium) diseases, but not enough to be of any economic importance. We have never observed any marked mortality due to these causes in Connecticut.

INSECTICIDES

The entomologists of the Hawaiian Sugar Planters' Experiment Station tried to protect sugar-cane from the attacks of the larvae of this insect by means of various insecticides. The injection of cyanide of potassium solution, seven ounces in one quart of water, by the Mamelle process was not successful (Muir, 1912 and Swezey, 1913) ; 20 cc. per stool of cane gave only 4.25 per cent kill of grubs. Gasoline injected at the rate of 20 cc. on four sides of a hill killed only 20 per cent of the larvae. Carbon disulfide injected at the rate of 10 cc. every ten inches in the row gave 95 per cent kill but was considered too expensive and possibly dangerous to the plants. After the success which accompanied the establishment of *Scolia manilae,* further control experiments were abandoned.

In Connecticut Zappe and Garman (1924) tried calcium cyanide, sodium cyanide, kerosene emulsion, bichloride of mercury, and carbon disulfide emulsion against the larvae. The cyanides killed the grubs but proved toxic to grass at a strength necessary to insure a heavy mortality of larvae, and kerosene emulsion and bichloride of mercury were considered of no value. Carbon disulfide emulsion proved successful. In 1926, Britton and Zappe reported further unsuccessful trials with calcium cyanide. There is no question of the ability of this poison to kill the larvae, but it cannot be safely applied to lawns. In 1926, Johnson, using methods of treatment with carbon disulfide emulsion developed at the Japanese beetle laboratory at Riverton, N. J., treated 43.5 acres of lawns in New Haven with an emulsion containing 70 per cent of CS_2 diluted 200 times with water. He secured a high mortality of larvae, up to 98 per cent in some cases, and did not injure the turf (Johnson 1927). It was found, however, that the use of carbon disulfide emulsion effected but a temporary relief, and that the following season the lawns became reinfested.* This treatment would have to be applied every year to be effective, and some skill is required to avoid injuring the grass. Leach and his collaborators at Riverton developed a means of treating turf with lead arsenate and thereby insuring it against damage by Japanese bettle larvae for some period of time. This method is well described by Leach and Lipp (1927) and by Leach (1928). Arsenate of lead is added to the top layer of soil and the larvae in this layer, eating

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*The lawns were treated in the spring and fall of 1926 and in the spring of 1927, and at the present time, fall of 1928, the population of larvae in the treated area, as indicated by the appearance of the lawns, is approximately the same as before treatment, although the infestation is more widely spread.

the arsenate, are thereby poisoned. A few lawns in New Haven were so treated, the acid lead arsenate being applied at the rate of three pounds to 100 square feet of surface and then worked into the upper two inches of soil with a hand rake. The ground was then seeded with one of the bent grasses, and a good turf resulted. The soil so treated has maintained a good turf for two years without further poisoning, and in New Jersey some of the plots treated by Leach in this manner have remained free of injury eight years.

According to the latest recommendations for grub-proofing golf greens with lead arsenate, the use of so much poison is not necessary against the Japanese beetle, and since the Asiatic beetle is closely related and of similar habits, less poison may possibly be effective against it in lawns. For newly constructed greens Leach (1928) recommends five pounds of lead arsenate to 1000 square feet of surface worked into the soil to a depth of ½ inch. It is necessary to add lead arsenate to future top dressings of soil. However, pot experiments with a limited number of larvae with poisoned soil indicate that 2.5 grams of lead arsenate per liter of soil is the minimum effective amount for the Asiatic beetle, and this is equivalent to 2.6 pounds per 100 square feet mixed into the top 2 inches. These experiments also show that the larvae of the first instar are more susceptible to this poison than are older larvae. The results of these pot experiments are given in Table 11. Flower pots having a diameter of six inches across the top were used, and ten larvae were placed in each pot. One control was kept for each lot, the soil not being poisoned. The mortality in this control was possibly due to handling and change of environ-

TABLE 11—EFFECT OF LEAD ARSENATE ON LARVAE

	FIRST INSTAR			SECOND INSTAR		
Lead Arsenate	No. of Larvae	Absolute Survival 10-11 days	Relative* Survival 10-11 days	No. of Larvae	Absolute Survival 12-16 days	Relative Survival 12-16 days
1 g. per liter	60	14 = 23%	48%	40	20 = 50%	77%
1.5 g. “ “	60	8 = 13%	27%	40	14 = 35%	54%
1.75 g. “ “	60	15 = 25%	52%	40	12 = 30%	46%
2.00 g. “ “	60	8 = 13%	27%	40	8 = 20%	31%
2.25 g. “ “	60	7 = 12%	24%	40	14 = 35%	54%
2.50 g. “ “	60	1 = 2%	3%	40	6 = 15%	23%
3.00 g. “ “	60	3 = 5%	10%	40	7 = 18%	27%
None	60	29 = 48%	100%	40	26 = 65%	100%

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*The relative survival has been computed by dividing the number of survivals in each test by the number of survivals in the controls.

ment, the larvae being taken from tiles containing growing sod; whereas, the pots contained no living grass. Each experiment was kept the same length of time, and the six lots with first instar larvae and four with second instar larvae were grouped in the compilation of results. There is little difference between the 2.50 grams per liter of soil and 3.00 grams per liter, but a noticeable difference between 2.50 grams and 2.25 grams. Another point worthy of notice is that whereas the larvae of the second instar were kept in the poisoned soil 12-16 days (the same soil was used for first and second instar larvae), they underwent a relative mortality of 77% and an absolute mortality of 85% in the 2.50 gram pots while the larvae of the first instar in the same poisoned soil suffered a relative mortality of 97% and an absolute mortality of 98%. The same general relations between the instars hold throughout the series. The relative mortality is figured on the basis of the survival in the control pots being 100%. The experiments were carried on in August and September, 1927.

This method of adding lead arsenate to the top layer of soil involves the rebuilding of the lawn at the expense of much labor, and a means of safe-guarding lawns in good condition was desired. Since the author above quoted has demonstrated the practicability of top-dressing turf with poisoned soil to protect it against Japanese beetle larvae, it was decided to try this method on the lawns in New Haven for protection against the Asiatic beetle. Two infested lawns were selected and a strip ten feet wide and thirty feet long was laid off on each. Each strip was then divided into three squares of 100 square feet each, the two end squares being treated and the center square serving as a check. In order not to mar the appearance of the lawn, it was decided to apply five top dressings of poisoned soil, each top dressing being one-fifth of one inch in depth, over a period of one year. This would give one inch of poisoned top soil applied to the lawn in the course of the experiment and, since the larvae feed close to the surface, should indicate the degree of protection afforded by the lead arsenate. Top dressings were applied November 10, 1927, and April 18, June 11, and August 15 in 1928. The last treatment was doubled, so that the top dressing was actually applied four times. Each application consisted of the lead arsenate mixed with 2880 cubic inches of soil except the last which consisted of the poison in 5760 cubic inches; 2880 cubic inches covers 100 square feet one-fifth of one inch deep. In no case was the appearance of the lawn marred. Plots were numbered 1, 2, and 3 in the first strip and 4, 5, and 6 in the second. Plot 1 received three ounces of lead arsenate per application, plot 3 received six ounces, and plots 4 and 6 received nine and 12 ounces respectively. At the close of the experiment the 100-foot plots had been given a top dressing of one inch of soil which contained 15, 30, 45, and 60 ounces of lead arsenate in the respective cases. The two check plots, numbers 2 and 5, received no treatment whatsoever. In all the treated plots the turf remained firm and in plots 3, 4, and 6, comparatively free of larvae. In both check plots the turf was soft, spongy, and well infested. The grass in plots 1 and 3 remained in good condition, whereas, much of that in 2 was killed. In plots 4, 5, and 6, the turf was mainly crab grass *Digitaria (Panicum) sanguinalis,* an annual, so that the appearance of the entire lawn was not good after the first of October. Fertilizer was applied to plots 1, 2 and 3 twice during the summer of 1928, the first time Nitrophoska and the second time ammonium sulfate. Plots 4, 5, and 6 were not fertilized.

October 8 and 9, 1928, diggings were made one foot square and one foot deep in the center of each plot and the number of larvae found were counted. The results are given in the table below. The figures in the last column were obtained by making one digging and, due to the spotted nature of infestations in general, may not be exact for the entire area used in the experiments. This also holds true for Table 13.

TABLE 12—EFFECT OF LEAD ARSENATE APPLIED IN TOP-DRESSING

Plot	Total lead arsenate in 4 applications	Larvae found per sq. ft. Oct. 8, 9, 1928 1st Instar	2d Instar	3d Instar	Total	Larvae per sq. ft. prior to treatment of lawn
1	15 ounces....	0	6	7	13	Oct. 11, 1927 24
2	none........	0	3	46	49	
3	30 ounces....	0	2	1	3	
4	45 ounces....	0	0	2	2	Oct. 14, 1927 36
5	none........	0	6	32	38	
6	60 ounces....	0	0	1	1	

Observations in the infested area indicate that good turf will withstand an infestation of about 150 larvae per square yard during one season if weather and soil conditions are favorable. From the above results it would appear that two pounds of lead arsenate to 100 square feet is an effective amount, but that one pound may be too little.

An easier method of protecting lawns against injury was tried, the lead arsenate being applied in water, ten to twelve gallons to one hundred square feet, and then washed in with an equal amount of water alone. The required amount of poison was mixed with water in an iron barrel and the resulting suspension applied slowly to the turf with a garden watering can. Before the suspension dried on the soil and grass, an additional ten to twelve gallons of water was applied in the same manner. This washed the poison off the grass and carried it into the ground. It was necessary to work slowly in order to prevent run-off. Four 100-foot plots were laid out, the first three in a row and each 10 ft. x 10 ft., the fourth on another lawn and 20 ft. x 5 ft. These were numbered 7, 8, 9, and 10 respectively. Plot 11 was the area in the lawn immediately surrounding plot 10. On plot 7 two pounds of lead arsenate were applied, on plot 9, three pounds, and on plot 10 three pounds of colloidal lead arsenate. Plots 8 and 11 were not treated but were used for check plots. The owner of the lawn in which plots 10 and 11 were located applied an inch of soil and fertilizer on plot 11, April 26, 1928, and seeded it. The arsenate was applied to plots 7 and 9 November 10, 1927, and to plot 10 April 18, 1928. The experiment was allowed to run until October 8-9, 1928, when the plots were examined for larvae in the same manner as were plots 1 to 6 above mentioned. Two ounces of casein-lime were added to the arsenate applied to plots 7 and 9, but this may not be necessary in view of laboratory experiments, and it may conceivably be detrimental. Plots 7, 8 and 9 were in the same lawn as plots 4 to 6 above and the turf was mainly crab grass, so that after October first none of these plots looked well as far as the appearance of the grass was concerned, although they could be easily distinguished from the check plots. The sod in the treated plots was firm, however, and comparatively free from larvae, whereas the sod in plot 8, the check plot, was soft, spongy, and well infested. Plot 10 maintained a fair turf as far as the appearance of the grass was concerned and plot 11 resembled plot 8, being soft and having very little live grass. Diggings made as previously October 8 and 9, 1928, gave the following results:

TABLE 13—EFFECT OF LEAD ARSENATE APPLIED IN WATER.

Plot	Lead arsenate applied*	Larvae found per sq. ft. Oct. 8, 9, 1928				Larvae per sq. ft. prior to treatment of lawn
		1st Instar	2d Instar	3d Instar	Total	
7	2 lbs........	0	1	9	10	Oct. 14, 1927 36
8	none........	1	8	64	73	
9	3 lbs........	0	0	1	1	
10	3 lbs........ (colloidal)	0	1	0	1	?
11	none........	0	2	36	38	

From the above results it seems that two pounds is only fairly effective when applied in this manner, but three pounds is very satisfactory. In none of these plots was the grass visibly injured by the treatment. It should be borne in mind that all the experimental plots, due to previous infestations of larvae, contained much crab grass, and a fair turf was the best result obtainable as regards the *immediate condition* of the lawn. Where the lawn is already in good condition, it will stay so after treatment.

The method of applying lead arsenate in water was checked by a laboratory experiment in which a shallow box was divided into

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*See page 656 regarding this column.

four compartments each one foot square and five inches deep. Each compartment was filled with soil to a depth of three inches and seeded with red top grass. When the grass was about one inch in height, the required amount of lead arsenate was mixed with 500 cc. of water and applied to the one square foot of surface. No additional water was used to wash in the arsenate because of the danger of flooding and getting an uneven distribution of poison. In each plot 100 first instar larvae collected in the field were placed between one and two weeks prior to the application of the poison. The larva were placed in the plots August 1-2, 1928, the lead arsenate was applied August 8-13, and the soil was sifted and examined for larvae September 18-19, 1928. This experiment was carried on in the laboratory. Three plots were treated with arsenate, 7 grams, 14 grams, and 21 grams respectively, and one plot was treated with tap water only, serving as a check. The results are given in the table below:

TABLE 14—EFFECT OF LEAD ARSENATE APPLIED IN WATER.

Lead Arsenate	Applied	Larvae in	Larvae recovered Sept. 18–19				Survival	
			1st	2d	3d	total	Absolute	Relative
None...	Aug. 13 (water)	100 Aug. 1	3	23	55	81	81%	100%
7 grams	Aug. 8	100 Aug. 1	1	6	9	16	16%	20%
14 grams	Aug. 13	100 Aug. 1	3	0	1	4	4%	5%
21 grams	Aug. 13	100 Aug. 2	0	1	3	4	4%	5%

Fourteen grams per square foot is equivalent to 49.4 ounces per 100 square feet, and this appears to be the minimum effective dose. All of the grass in these four plots was affected by damping off, so that the effect of the arsenate on the turf itself could not be determined. In preparing South German creeping bent sod for use on terraces no injury to the grass was visible after treating in the above manner, and at present this appears a safe method. Other lawns in New Haven have also been so treated without visible injury.

It is not known how long the lead arsenate will remain in the soil in effective amounts nor whether or not there will be an accumulation of lead due to these treatments. The field plots 7, 8, 9, 10, and 11 were sampled April 17, 1928, and the soil analyzed for arsenic content, the first three inches of soil being used. The same plots were again sampled in a similar manner October 4, 1928, and again analyzed for arsenic. The determination of the per cent of arsenic should give an indication of the distribution of the poison throughout the top three inches of the soil and of the rate at which the lead arsenate is breaking down and being removed by water from the surface layer. This determination might not be a reliable index of the toxicity of the poisoned soil to the larvae, since this depends somewhat on a number of factors concerning which there is little available information, nor would it indicate the arsenical compound present in the soil. The results are given below:

TABLE 15—ARSENIC IN SOIL AFTER TREATMENT.

Plot	Lead Arsenate	Applied		As_2O_5* Apr. 27, 1928	As_2O_5* Oct. 4, 1928	Ph Oct. 4, 1928
7	2 lbs. + 2 oz. casein lime in water	11-10-27	1″	0.081%	0.087%	6.21
			2″	0.008	0.009	6.02
			3″	0.005	0.010	6.45
8	none—water only, check on 7 and 9	11-10-27	1″	0.005	0.000	6.80
			2″	0.001	0.005	6.49
			3″	0.000	0.000	6.09
9	3 lbs. + 2 oz. casein lime in water................	11-10-27	1″	0.070	0.070	6.31
			2″	0.017	0.006	6.29
			3″	0.003	0.005	6.08
10	3 lbs. colloidal in water**	4-18-28	1″	0.128	0.035	5.40
			2″	0.001	0.017	5.61
			3″	0.012	0.001	6.00
11	none—check on 10		1″	0.005	0.003	5.59
			2″	0.001	0.006	5.55
			3″	0.012	0.000	5.65

The analyses were made on an air-dry basis by the Gutzeit method, and the soil samples were all taken from plots which were treated with a suspension of lead arsenate in water. Three samples were taken from each plot and mixed together to get the plot sample. In getting the soil sample, a cylinder of soil was removed and the upper three inches cut into three one-inch slices. The analyses were made for each of the first three inches of soil. The colloidal lead arsenate was procured from a New York agent of the manufacturer and is much more finely ground, although less bulky, than the commercial acid lead arsenate used in the first two plots (7 and 9). The collodial form also stays in suspension in water longer than the other. The reason for the great decrease in arsenic in the soil poisoned by the colloid form of lead arsenate may be due to the nature of the soil or of the arsenate. Plots 10 and 11 were in one lawn and plots 7, 8, and 9 in another, and in the former case the acidity was much greater than in the latter. The analyses also show less arsenic in the plot treated with three pounds (9) than in the plot treated with two (7), a matter for which the explanation cannot be satisfactorily given at present. The important facts of the analyses are, however, that there was no appreciable decrease in the arsenic content of the soil in plots 7 and 9 during one season, and that in the acid soils of the kind

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*Analysis by Mr. H. J. Fisher of the Chemistry Department.

**This colloidal lead arsenate contains 27.06% As_2O_5, 2.16% water soluble As_2O_5, 59.96% PbO.

used in the experiment the addition of lead arsenate caused very little permanent increase in acidity.

The results of these experiments indicate that if the lawn is to be treated by lead arsenate suspended in water and applied as indicated, or by mixing the lead arsenate in the top two inches of soil, then three pounds per 100 square feet of lawn is the most efficient amount of poison to be used. For top dressing the lawn with poisoned soil, two-thirds of this amount, or two pounds per 100 square feet in one inch of top dressing, is best. The successful use of less poison in top dressing is probably due to the greater concentration of poison in the top inch of soil where it is most effective. When applied in water, much of the poison probably remains on the surface of the soil and is not there available. No experiments have been carried on wherein the lead arsenate was mixed with the upper inch or half-inch of soil, but in view of the results attained by top dressing, it would seem advisable to reduce the poison to two pounds per 100 square feet and work it into the top inch when the lawn is being rebuilt. An analysis of the soil of a lawn treated by mixing the arsenate in the upper two inches, three pounds to 100 square feet, showed 0.070% $As_2 O_5$ in the upper inch, 0.046% in the second inch, and 0.017% in the third inch five months after treatment. Granting an equal relative decrease in arsenic in each of the upper two inches of soil, it appears that under field conditions the upper inch receives about three-fifths of the arsenic by this method of treatment. The mechanical difficulties of mixing arsenate in the soil by this method preclude an even distribution in both the upper inches. This lends support to the conclusion that two pounds of lead arsenate mixed in the upper inch are enough. The larvae feed close to the surface of the soil and no poison is necessary below a depth of one inch.

Although it may be possible to still further modify this method according to the recommendations of Leach (1928) given above since the experiments in New Haven cover one season only, whereas the work of the above author covers a number of years, such modification is not recommended for the Asiatic bettle at present.

Among other chemicals tried against the larvae were potassium xanthate, Semesan*, Uspulun*, Uspulun Nu-Green*, and potassium sulfocarbonate. None of these materials proved effective in the brief experiments carried out, but potassium sulfocarbonate merits further trials.

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*Semesan and Uspulun contain 30% hydroxymercurichlorophenol sulfate, and Uspulun Nu-Green contains 15% of the same compound. The remainder of each of these three materials is inert matter.

Recommendations for Control in Lawns

If the lawn is in good condition and it is desired to protect it against future attacks by the larvae, arsenate of lead suspended in water, three pounds to about 12 gallons for each 100 square feet, should be applied before August 1. The lawn should be sprinkled with the suspension slowly and evenly so that it soaks in without puddling or running off. Before the suspension dries on the grass and soil, an additional 12 gallons of water should be applied in the same manner to the same area. If the ground slopes or is uneven so that the suspension runs off or collects in pools, the lead arsenate should be mixed with a small amount of very slightly moist (not wet) earth and spread evenly over the surface. If it is desired to top-dress the lawn, apply the top dressing at the rate of six ounces of lead arsenate to each 2,880 cubic inches (=12.5 gallons or 1.34 bushels) of top-dressing on each 100 square feet. Five applications should be made, and it is advisable to have an inch of top dressing on by August 1. The interval between applications depends on the rapidity with which the grass grows.

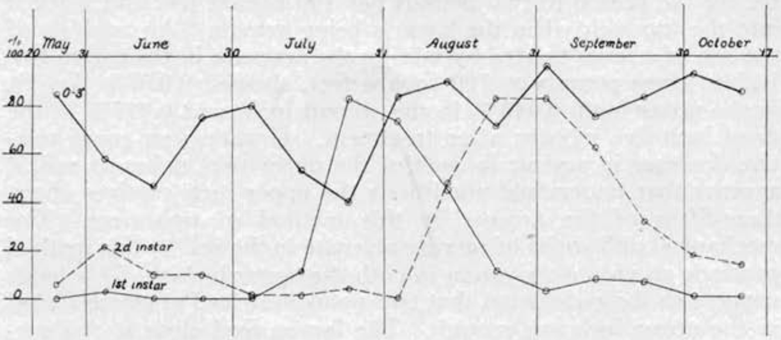

FIG. 56. Larvae in upper three inches of soil and in first and second instars.

In Figure 56 are given the curves showing per cent of larvae above a depth of three inches in the soil throughout the growing season and the percentages of larvae in the first and second instars. These curves are superimposed in order to show the necessity for treating the lawns by August 1. On August 15, or thereabouts, 90 per cent of the larvae are in the upper three inches of soil; between 40 and 44 per cent are in each of the first two instars. This means that practically all the eggs are hatched and the larvae are feeding near the surface of the soil at this time. The younger larvae are much more easily killed than the older larvae, and the treatment should be applied with this fact in mind. Also it is quite evident from field observations that the grass is not severely injured before August 1.

If the grass has been killed by the larvae, it is advisable to spade up the lawn in order to get rid of the weeds and insure a good turf. After spading, smooth the lawn with a rake and apply two pounds of lead arsenate to each 100 square feet. In order to get an even distribution of poison the arsenate should be applied by sifting through a 14-mesh screen, but if a wind is blowing, better results are obtained by thoroughly mixing it with a small amount of slightly moist earth (*not wet*) and spreading the resulting mixture. After spreading evenly, work the material into the ground to a depth of one inch with an iron rake, smooth over and seed. Where the infestation of larvae is not too heavy, good control might be effected by raking over the infested area in the spring, seeding it, and then, after the grass is growing well, applying lead arsenate in water in the manner described above. There is, however, the likelihood that the larvae will kill off this grass before it gets a good start and that weeds will crowd out the lawn grasses. One treatment with arsenate of lead should last several years, although the experiments with the Asiatic beetle have covered one season only. The soil analyses given on page 656 indicate that the arsenate is removed from the soil very slowly. Any top-dressings applied to the lawn should contain lead arsenate in the proportions given.

Carbon disulfide emulsion, containing 70 per cent carbon disulfide, diluted 200 times with water and applied at the rate of three pints of diluted material per square foot of lawn surface will kill the larvae if they are within two or three inches of the surface when the lawn is treated. This treatment should be applied the latter part of August and the soil should not be extremely dry nor yet full of water. The use of this material has several drawbacks. It is but a temporary treatment at best and its effect is over in a short time. If care is not used it will severely injure the grass, and it cannot be stored near fires or hot pipes, being highly explosive. A miscible carbon disulfide is now on the market and is a very superior product as regards keeping qualities, not being injured by cold weather and long storage. It contains 70 per cent carbon disulfide and is used as above indicated. The use of carbon disulfide is fully described by Leach, Lipp, and Fleming (1927).

If the lawn slopes so steeply that it is not feasible to seed it, poisoned turf should be used to replace that injured. The turf may be poisoned a few weeks prior to the time when it will be used by a suspension of lead arsenate in water applied as described above. Cut the poisoned turf into sections and lay it in the lawn in the usual manner.

FERTILIZATION AND SEEDING

Fertilizer should be applied after the lawn is treated with arsenate, and after the grass is growing well if the lawn has been reseeded, as there is danger of injuring the grass if the fertilizer and arsenate are applied at the same time. A week later should be sufficient. Any of the usual lawn fertilizers should give good results, but those high in phosphoric acid should be avoided. In our experiments we have used both ammonium sulfate and a complete fertilizer.

The grass mixtures commonly sold in New Haven for seeding lawns give a good turf on arsenated soils if the soil is fertile. It is best to seed rather heavily. The germination of the seed may be retarded by the arsenate but no permanently injurious effect will result.

TREATMENT OF NURSERY PLANTS

For the treatment of nursery stock, potted plants, and plants with soil about the roots it is best to follow the procedure for the control of the Japanese beetle as given by Leach and his collaborators, Fleming, and Lipp, references to which may be found in the bibliography.

SUMMARY

The Asiatic beetle, first described in 1875 from Japan, was discovered in Connecticut in 1920 and has since been found in parts of New York and New Jersey. The natural spread of this insect is very slow.

A brief review of natural conditions in New Haven is given.

The genus Anomala belongs to the Ruteline Scarabaeidae, and the structural characters distinguishing the larva from other related larvae are described. A brief morphological description is given of all stages of the insect.

In New Haven the great majority of individuals of this species go through a complete life cycle in one year, but a few require two years for the completion of development. The adults emerge from the pupal stage late in June and during July and August and oviposit in the soil at a depth of about six inches. The eggs hatch in three to four weeks and the young larvae move up close to the surface of the soil where they feed on grass roots and decayed organic matter. In September and October the lawns in heavily infested areas are severely injured and the grass in spots completely killed. Late in October and during November the larvae descend into the soil to a depth of about one foot to hibernate, most of them being at this time in the third larval instar. The last of April the larvae come up close to the surface and re-

sume feeding, and the first of June they go down again to a depth of about six inches to pupate. After a prepupal period of about six days they molt and the pupal stage begins. This lasts about two weeks.

There is at present no effective natural control of this insect in New Haven, and reliance must be placed on insecticides. Lead arsenate and carbon bisulfide have given good control in lawns where properly applied. The latter is used in the form of an emulsion containing 70% CS_2 diluted 200 times with water and applied at the rate of three pints of diluted material per square foot of surface. This insecticide is effective for a short time only, however, and lead arsenate gives a more permanent control. This may be applied to the surface of the lawn at the rate of two pounds per 100 square feet of surface and worked into the soil to a depth of one inch. It may be used in a top-dressing of loam at the same rate, or it may be applied as a suspension in water at the rate of three pounds per 100 square feet of surface.

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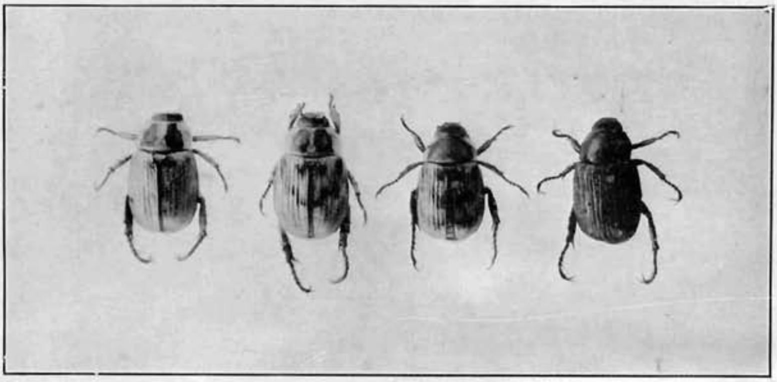
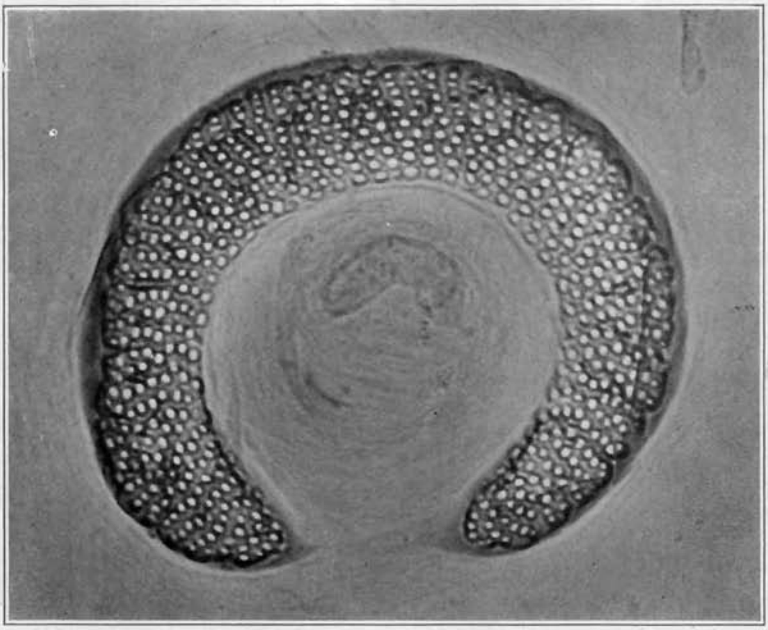
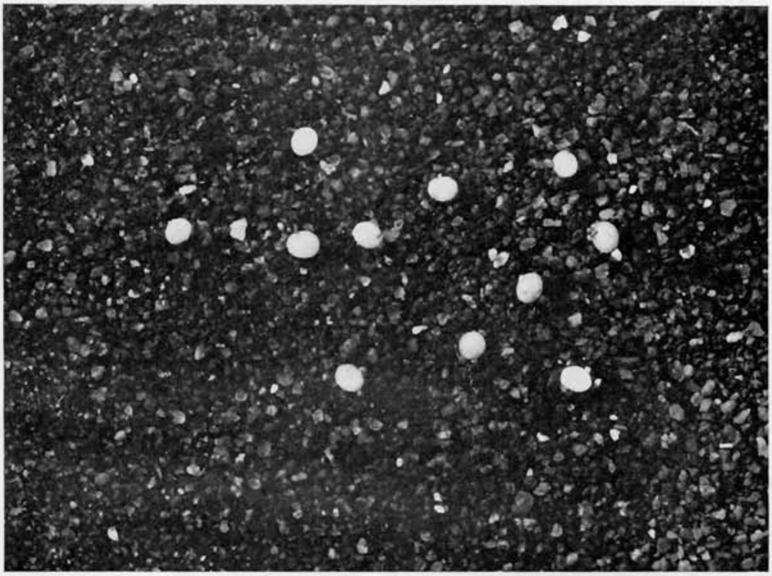


a. Adults of the Asiatic beetle (*Anomala orientalis* Waterh.). Enlarged twice.



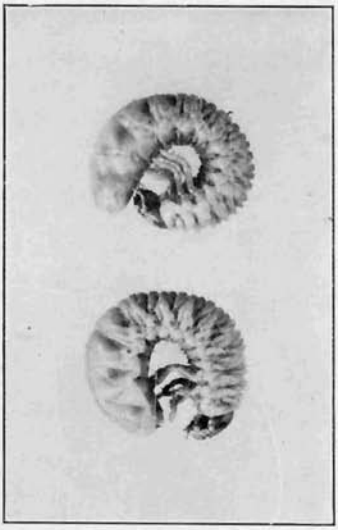
b. Spiracle of larva. Greatly enlarged.

PLATE XVIII



a. Eggs. Enlarged four times.

b. First instar larvae. Enlarged four times.



c. Third instar larvae. Enlarged twice.

PLATE XIX

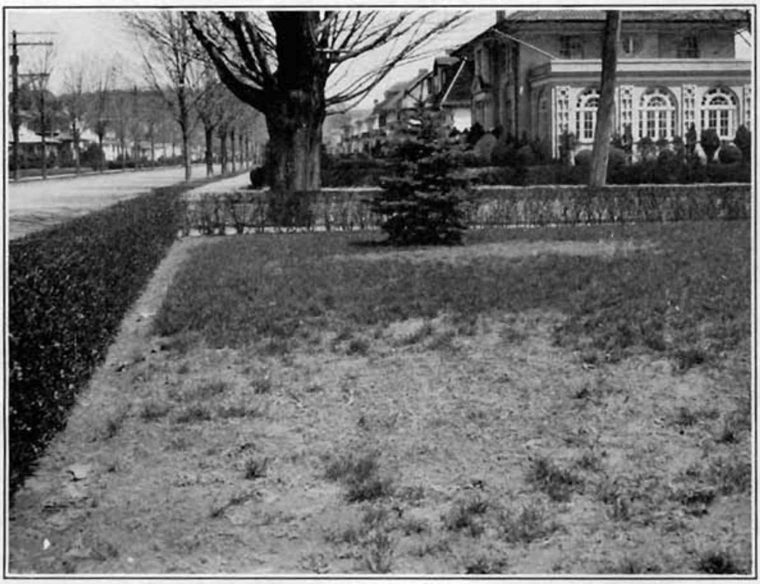
a. Prepupa. Enlarged four times.

b. Pupa in cell in earth. Natural size.

c. Pupa in cast larval skin. Enlarged 2.5 times

d. Pupa. Enlarged four times.

PLATE XX



a. Lawn injured by larvae.

b. Holes in ground made by adults.