ON THE BIOLOGY AND CONTROL OF THE NORTH AMERICAN CHESTNUT WEEVILS

by

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ABSTRACT

Title of Thesis: On the Biology and Control of the North American Chestnut Weevils

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Curculio auriger (Casey) and Curculio proboscideus Fab. are indigenous North American nut weevils and attack only the fruits of chestnut and chinquapin. Their natural distribution occurs over the same geographical areas that the American chestnut was found. Since the destruction of most of the native chestnut trees by chestnut blight, Endothia parasitica (Murr.), the weevils have been able to survive on scattered plantings of oriental chestnuts which are resistant to blight, from a few native chestnut trees partially resistant and from the coppice growth of old chestnut stumps.

Rearing of both species in the field was accomplished by the use of soil cages set into the ground to a depth of 12 inches. Adult behavior was studied in large cages that completely covered the tree.

Chestnut weevils lay their eggs in the kernel. The eggs of C. auriger hatch in about eight days and those of C. proboscideus hatch in about 10 days under the conditions in central Maryland. There are four larval instars in each species and these are described and illustrated. Head characters were found that will separate the species and the

instars. *C. auriger* completes its larval development in 21 days while it takes 30 days for *C. proboscideus*.

The pupae of both species are of the exerate type and may be separated by the presence of two small bristles on the beak, near the insertion of the antennae, of *C. auriger*. These bristles are lacking in *C. proboscideus*.

The usual life cycle of *C. auriger* is two years. The life cycle of *C. proboscideus* is usually one year. A few individuals of each species require an additional year to complete their cycle. The adult *C. auriger* issues from the ground in May and feeds on the chestnut catkins. After the catkins wither they disperse and are not seen again until the chestnuts are nearing maturity. *C. proboscideus* issues from the ground late in July and may be seen in the trees a few days after emergence.

The male genitalia were studied for taxonomic characters. These characters are sufficiently clear so that the two chestnut weevils may be identified thereby.

Two species of internal insect parasites were found. *Myiophasia nigrifrons* Tns., a tachinid fly, was reared from the larvae of both species of chestnut weevils and was observed in its larval stage within the body cavity of the chestnut weevil larva. *Urosigalphus armatus* Ashm. is a braconid parasite and was found only in the larvae of *C. proboscideus*.

Chemical control studies have shown that the adult stage is the most susceptible to insecticides. Preliminary tests with heptachlor, applied at the rate of six to eight pounds of the chemical per acre, as a spray or dust to the ground cover under the trees, have given excellent results for the control of chestnut weevils.

ACKNOWLEDGEMENTS

The writer wishes to express his thanks to Dr. E. N. Cory for creating the initial interest in this research and for his assistance throughout the course of investigation. As with all major undertakings assistance was rendered by many individuals. Doctors Harley L. Crane, J. W. McKay, G. F. Gravatt, F. H. Berry and others of the Department of Agriculture section of Fruit and Nut Investigations have helped in many ways, the most important of which was the chestnut orchard that was given over to this project.

Thanks to Mrs. Ernestine Thurman for allowing me to use the optical equipment assigned to her, for without it most of the drawings and dissections could not have been made.

All the chestnut growers called upon were eager to participate in control studies and assisted greatly in these matters.

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CHAPTER I

INTRODUCTION

Sometime prior to 1904 a destructive disease of chestnut trees caused by Endothia parasitica and known as the chestnut blight was accidentally introduced into the United States from China. The disease was first discovered in the New York Zoological Park. From that center it spread into forests of native chestnut, and in less than 50 years blight reached every part of the natural range of the American chestnut. The virulence of the blight and susceptibility of the four Eastern species (Castanea dentata, American chestnut; C. pumila, Allegheny chinquapin; C. alnifolia, Alder leaved chinquapin; C. ozarkensis, Ozark chinquapin) has brought about a rapid destruction to these trees which is well remembered in the agricultural history of our nation.

Much work has been done to produce desirable chestnut trees that will replace the native chestnuts killed by disease. The goal of plant breeders, working with chestnuts, is to produce trees and nuts like the native trees. Some success has been attained by selective breeding but as yet the U. S. Department of Agriculture has not released for general distribution an entirely satisfactory hybrid tree.

However, experiments with several species of oriental trees have led to the general acceptance of certain varieties of Castanea mollissima commonly known as the Chinese chestnut. Several varieties of this species have been planted throughout the country, and in several eastern states nuts are being produced commercially. The older orchards have been the sources of thousands of pounds of seed which have been sold for as much as $1.65 per pound. These older orchards are now being plagued with several insect pests. The most important ones are Curculio proboscideus Fab. and Curculio auriger (Casey). These two species are major factors in profitable chestnut growing. An economical means of control has been greatly desired, and the need has stimulated much of the research reported herein.

There are about 100 growers of chestnuts in the state of Maryland. Production estimates are difficult to make due to the many thousands of pounds of nuts that are never harvested because of nut weevil infestation. Approximately 14,000 pounds of nuts were produced by commercial orchards in the state in 1955 and about 8,000 pounds of the above figure were sold as seed. There are seven known chestnut plantings in the state that have been abandoned due to the difficulty of producing worm free chestnuts. The market for domestic chestnuts is increasing yearly since the production of European chestnuts is on the decline due in part to chestnut blight in Europe. It is believed that nut raising can be profitable in Maryland provided insects and disease are economically controlled.

The data submitted in this thesis represent four years of experiments and field observations. These were made in two of the U. S. Department of Agriculture chestnut orchards near College Park and in numerous private plantings in various parts of the state.

In addition to the chestnut weevils nine other species of insects and mites have been found to feed on the nuts or foliage of chestnut. Only two of these are economically important.

CHAPTER II

CHESTNUT BLIGHT AND THE CHESTNUT WEEVILS

There are three native *Castanea* species in which chestnut weevils will lay eggs. After the blight killed the majority of these trees there was undoubtedly a great reduction of both species of weevils. In many areas where chestnuts were apparently wiped out by blight the question has frequently arisen as to how the weevils could survive. There is no evidence in the literature, or from experiments in this study, that chestnut weevils will lay their eggs in any nuts other than the fruits of chestnuts and chinquapins, yet within two to four years after young blight resistant chestnut trees come into bearing the nuts are found infested with weevil larvae.

The only explanations that can be offered are that they are capable of surviving on chinquapins, from scattered plantings of Oriental chestnut trees which are blight resistant, and from native chestnut trees still living and producing nuts.

Ten native chestnut trees have been found that are 40 years old or more. In wooded and isolated areas there are undoubtedly hundreds of chestnut sprouts or coppice growth from old chestnut stumps that may survive blight long enough to produce fruit. In 1955 about eight young sprouts were found near Hancock, Maryland, four of which were bearing nuts. Discussions with several farmers in the area revealed the rather common occurrence of young coppice growth of chestnuts. Although these trees do not live very long due to blight it seems to be sufficient time to keep the weevil species numerous in the area.

That Curculio auriger is capable of rather lengthy flight seems certain. At the Prospect Plantation Orchard, near Graysonville, Maryland the small chestnut weevil was found for the first time in 1949. These trees had been producing nuts about four years. The orchard is bordered on the west by the Chesapeake Bay and on the south and southeast by a rather extensive marsh. The nearest wooded area is approximately one mile to the northeast. No chinquapin or chestnuts have ever been known in this area. The only access to this orchard would require the adults to fly at least two miles.

CHAPTER III

NATURE AND EXTENT OF INJURY

The injury to chestnut fruits is caused by two very similar species of weevils which lay their eggs inside the nuts while they are growing or after they are ripe. These eggs hatch and the larvae feed upon the kernel until they are fully developed during which time the kernel of the infested nut is usually entirely devoured. Any portion not eaten is of little or no value. Weevil injury varies greatly in different chestnut growing localities but the variation is mostly due to the age of the planting and thoroughness of the insect control program. It is not unusual for 50 to 75% of the nuts to be wormy and often infestation reaches 90 to 100%. Usually the small weevil *Curculio auriger* does the most damage since it reproduces in larger numbers. In one orchard in Calvert County it took only two generations of *C. auriger* to produce 95% infestation of the nuts. In most of the Maryland plantings *Curculio proboscideus* has not been found.

Injury by the chestnut weevils is not limited to that done by the larvae. Feeding injury by the adults provides a means for the entrance of fungus and yeast organisms. These organisms cause the kernel to decay and are seldom noticed until after the nuts are placed in storage.

The adult *C. auriger* has been observed to feed on the catkins in the spring but it is doubtful that any appreciable damage is caused.

A few chestnut plantings were surveyed during 1954 and 1955 to determine the degree of infestation and whether or not chemical control measures were taken. The results of this survey are found in Table 1. Older plantings that have been producing nuts for six or more years all have weevils. Trees that have been producing only two or three years rarely have weevils.

Table 1

CHESTNUT WEEVIL INFESTATION IN 1954, 1955 SURVEYS

County	Grower	Chemical Treatment	Percent Infestation 1954	Percent Infestation 1955
Queen Anne	Edels	yes	10%	2%
Queen Anne	Moore	yes	10%	0
Montgomery	Horine	yes (1955 only)	85%	0
Kent	Owens	yes (1955 only)	95%	95%
Kent	Andelot Farms	no	0	0
Cecil	Toms	yes (1955 only)	90%	85%
Caroline	Tribbitt	no	100%	90%
Montgomery	Bennett	no	95%	70%
Montgomery	Porter	no	80%	70%
Somerset	Kemp	yes	1%	1%
Calvert	Truman	no	85%	85%
Calvert	Buckler	no	0	0
Talbot	Heming	yes	2%	2%
Calvert	Lore	no	70%	95%
Charles	Sullivan	no	10%	-
Charles	Smith	no	0	0

CHAPTER IV

METHODS FOR REARING

The rearing of chestnut weevils was not difficult but required a great deal of work in the preparation of suitable cages. Rearing was accomplished under both laboratory and field conditions. However, laboratory rearing was not practical. The field (Fig. IV) larvae cages consisted of two wood frames each three feet square and three inches high clamped on top of each other. The top frame acted as a lid and was covered with 16 mesh aluminum screen. Copper screen was tacked around each side of the lower frame and extended 12 inches below its lower edge. A narrow trench about 12 inches deep was dug in the ground, of the same square dimensions as the frame. This screen was then placed in the trench and the soil replaced. The underground screen was necessary to keep out moles and shrews. Ten larvae rearing cages were prepared in this manner and proved to be the most satisfactory type cage. Infested nuts were placed inside the cage for normal emergence.

Large scale rearing was attempted by using 50 pound lard cans with holes punched in the bottom. These cans (Fig. IV) were buried in the ground leaving only the top rim visible. The cans were filled with soil and tamped down lightly which left sufficient room to heap about 15 pounds of infested nuts. This method was not successful because the water drainage was not rapid enough and caused the larvae to drown.

Two tree cages (Fig. IV) were also built for closer observation on the behavior of the adult weevils. The cages were built of a semi-permanent nature. The frame was constructed of 2 x 4's and covered on the sides with plastic screen and on top with aluminum screen. The dimensions of the smaller cage were 10 x 10 x 12 feet. The tops were made in three sections and are portable; in that they may be removed so that natural cross pollination by insects will not be impeded. An 18 inch trench was dug around the base of the cages and hardware cloth was placed in the trench and tacked to the wood structure. The soil was then replaced so that the wood base was in contact with the soil. This arrangement prevented moles and shrews from tunneling into the cage and prevented curculio adults from getting out at the soil level.

CHAPTER V

HISTORY AND TAXONOMIC POSITION

The coleopterous genus *Curculio* formerly known as *Balaninus*, comprises a well defined group of species which includes the nut weevils. The distinguishing characters of the genus are the extremely long and slender rostrum, or beak, and the vertical mandibles.

The genus *Curculio* was proposed by Linnaeus in his 10th edition of Systema Naturae, 1758, and Latreille in 1810 designated *nucum* L. as the type. *C. nucum* is one of the major pests of chestnuts in Southern Europe. This generic name was apparently overlooked by coleopterists until W. D. Pierce (1925) called attention to it. Chestnut weevils are classified as follows:

Order: Coleoptera
Family: Curculionidae
Tribe: Curculionini
Genus: Curculio

Curculio proboscideus was described in 1775 by Fabricius. In 1910 Casey described *Curculio* (*Balaninus*) *auriger*. The large number of synonyms of both species gives evidence in the difficulty of identification because of variations within the species. Horn wrote in 1873, "The marked uniformity of vestiture of many of the (*Curculio*) species renders it extremely difficult to separate them." Many of the early descriptions were based on specimens that were more slender or stouter or more nearly cylindrical than others, or with a little shorter or a little longer rostrum, or antennae with different curvature or vestiture. With descriptions based on these characters it is little wonder that there are large numbers of names that should be sunk in synonymy.

Three synonyms of *C. proboscideus* have been recorded by Chittenden (1927) and two of these were described by Casey. Eight synonyms were found of *C. auriger* and seven of these were names proposed by Casey. Many synonymous names are to be found with all the nut weevils so that in the older literature it is difficult to determine what species an author was discussing unless the host was mentioned. In Blatchley's (1916) work the name *algonquinus* was used for *auriger*. Using the keys without some knowledge of the host is extremely difficult for the nut weevils as a group.

The following names are synonyms of *Curculio proboscideus* Fab. 1775 as recorded by Chittenden (1927).

1.	*Balaninus caryatrypes*	Bohm 1845
2.	*Balaninus hariolus*	Casey 1910
3.	*Balaninus cylindricollis*	Casey 1910

The following names are synonyms of *Curculio auriger* (Casey) 1910.[1]

1.	*Balaninus rectus*	Horn 1873
2.	*Balaninus auriger mollis*	Casey 1910
3.	*Balaninus strigosus*	Casey 1910
4.	*Balaninus algonquinus*	Casey 1910

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[1]A personal communication from E. L. Sleeper, Ohio State University.

5. *Balaninus acuminatus* Casey 1910
6. *Balaninus setosicornis* Casey 1910
7. *Balaninus macilentus* Casey 1910
8. *Balaninus perexilis* Casey 1910

Specific relationships of several nut weevils of hickory and chestnut have been clarified by biological and rearing studies. There has been very little work done on the genitalia of this group. Bissell's work of 1937 on the genitalia of the pecan weevil is the only one the author has been able to find on this genus.

Chittenden (1927) described 39 species of *Curculio* in Boreal America and provided keys. Some of the specimens that the author has taken in Maryland can be identified very well with these keys but others could not be identified to species even with the assistance of taxonomic specialists.

There are 13 species of *Curculio* nut weevils reported in Maryland but only six definitely determined by the author or U.S.D.A. specialists.

Species of *Curculio* Reported in Maryland		Host
proboscideus	Fab.*	chestnut, chinquapin
auriger	Casey*	chestnut, chinquapin
nasicus	Say*	acorns, *Q. rubra*, *coccinea*, *alba*
caryae	Horn*	hickory, pecan
rectus	Say*	shagbark hickory--first account acorns of *Q. rubra*, *coccinea* and others
longidens	Chttn.	acorns of *Q. rubra* and *alba*
orthorhynchus	Chttn.	acorns of *rubra* and *coccinea*
pardalis	Chttn.	acorns of *velutina*, *alba*
strictus	Casey	acorns of *alba*
confusor	Ham.	acorns
baculi	Chttn.*	acorns of *alba*, *rubra*, *coccinea*, others
obtusus	Blanch.	hazelnuts
iowensis	Casey	acorns of *alba*

Those marked by an asterisk have been found by the writer.

CHAPTER VI

CURCULIO PROBOSCIDEUS FAB.--DESCRIPTIONS AND OBSERVATIONS

1. The Egg. The egg of *C. proboscideus* is about 1.2 mm. in length and 0.8 mm. at its widest point. There is some slight variation in shape but most are pear shaped. When first laid the egg is weakly opaque but becomes transparent. Embryological development may be easily followed through the transparent chorion and seems to be good material for this type of studies. The chorion is lightly sculptured with pimples which under high magnification makes the egg appear rough. They can be separated from *C. auriger* eggs by size. It takes about 10 days for the eggs to hatch.

The eggs are always found just under the thin brown skin of the kernel. They are laid singly in a hollow cavity at the base of the puncture. The cavity seems to be made of mulched, dark brown, necrotic nut tissue. It becomes hard shortly after the egg is laid and is 1 to $1\frac{1}{2}$ mm. thick. This cavity at its opening to the tubular puncture is frequently sealed by a rather pliable transparent membrane which is probably secreted by the female at the time of egg laying. This membrane suggests that an effort is made to stop the entrance of parasitic enemies.

2. The Larva. Cotton (1929) gives a technical description of C. proboscideus, and much of this description applies to all species of nut weevils studied and observed in this work.

The larvae of C. proboscideus are legless, "C" shaped and whitish in color in all stages. The head is dark yellowish brown, heavily sclerotized and has characters distinguishing the two species of chestnut weevils in all stages. The thorax and abdomen go through very little change in form other than size. The mandibles are very dark brown and help to distinguish the two species. In all stages the teeth of the mandibles are deeper than those of C. auriger. There is a pair of stemmata on each side near the antennae reduced to pigmented optical spots. There are three distinguishable thoracic segments with a pair of spiracles on the prothorax only. This pair of spiracles is larger than those on the abdominal segments and oriented so that the long axis is in a nearly vertical plane. The first 8 abdominal segments are very similar in form, shape, and size, each with a spiracle along the midline with the finger-like projections pointing posteriorly. All the spiracles are of the biforous type which is typical in coleopterous larvae. The last two segments are modified and reduced in size.

After hatching, the larva may stay in the nut from six to 10 weeks but larvae development lasts about 30 days. A statement as to the length of the period of each instar is difficult, and a theory based partly on experimental data is presented in the section on C. auriger larva.

The first instar lasts about six days, and the second and third instars each last about eight days. The period of the fourth instar while in the nut normally lasts about eight days. Occasionally the fourth instar larva cuts a hole in the shell and remains in the nut in a quiescent condition for several days provided there are no other weevil larvae sharing the nut.

On September 19, 1955, 50 infested Chinese chestnuts were collected for emergence records. The first, C. proboscideus larva emerged on September 21st. The greatest number emerged on October 9th and the last larva emerged on October 29th.

Both species of weevil larvae may be found in the same nut. The largest number of C. proboscideus larvae found in a single nut was three. Larvae of this species occasionally issue and drop to the ground before the nuts fall from the trees. This was observed to be the normal behavior of the pecan weevil larvae Curculio caryae (Horn) attacking both pecan and hickory nuts.

In the investigation of the larval stage, four instars were determined by measurements of head capsules and corroborated by finding the moulted head capsules in the frass. Since the head of most insects is quite hard and practically changeless from one instar to another, measurements were taken of certain head characters. Two conditions were considered necessary for a character to be valid in determining the number of instars: (1) the rate of growth should be great and (2) the rate of variation should be small. Measurements of width and length of the head, length of the mandible and length of the stigmata fit these conditions. However, measurements of the stigmata were not taken due to their small size especially in the first instar. There were no observed differences in the two mandibles, but for uniformity, measurements were recorded only of the right mandible.

First Instar. The first instar larva is about one mm. long. Its head is quite large in proportion to the rest of its body. For the most part it is a miniature of the mature larva but none of the bristles normally found on the head and body are visible at this stage, and not all the abdominal stigmata are visible.

The measurement of certain characteristics are found in Table 2.

Table 2

VARIATION OF THE HEAD CAPSULE OF FIRST INSTAR *Curculio proboscideus*

Class (mm)	Frequency Head width	Class (mm)	Frequency Head length	Class (mm)	Frequency Mandible length
.440	6	.310	2	.140	6
.450	4	.320	8	.150	4

Class range .010 mm. Class range .010 mm. Class range .010 mm.

As is indicated in the table there is very little variation within a character, and the rate of growth, at the first moult, is great enough to distinguish specimens falling within these ranges as first instar. It should also be noted here that the head width is greater than the head length. In the nut the first instar makes a tunnel about 10 mm. long before moulting and the tunnel is enlarged at the point where moulting takes place. Here the sloughed off mandibles and head capsule may be found.

Second Instar. At the second instar the head is still proportionally larger than the remainder of the body. The head capsule appears more like that of the full grown larva, and many of the bristles are visible both on the head and body. All the stigmata are visible. In tracing larval growth in the nut, the frass of the first instar is yellowish in color and after moulting the frass appears light brown in color, and the nut itself takes on a musty odor.

The measurements of the head characters are found in Table 3.

Table 3

VARIATION OF THE HEAD CAPSULE OF SECOND INSTAR *Curculio proboscideus*

Class (mm)	Frequency Head width	Class (mm)	Frequency Head length	Class (mm)	Frequency Mandible length
.680	-	.570	-	.190	-
.690	3	.580	1	.200	2
.700	3	.590	1	.210	0
.710	2	.600	1	.220	1
.720	0	.610	3	.230	3
.730	1	.620	2	.240	6
.740	0	.630	1	.250	-
.750	1	.640	1		
		.650	-		

Class range .06 mm. Class range .07 mm. Class range .040 mm.

In this group of measurements the range is greater in all characters. At this stage the mandible character begins to be recognized as the best character for determining the instar since the range is only .04 mm.

Third Instar. The third instar larva is much like that of the mature larva. In this stage it may be confused with the mature larva of C. auriger. The two may be separated by the presence of a rather distinct adfrontal area in C. auriger, which is completely lacking in C. proboscideus. Examination of the nut reveals dark colored frass and an enlarged tunnel where the moult takes place. The moulting of the head skeleton starts near the vertex with the old skeleton splitting at the upper end of the epicranial suture. The epicranial suture according to Snodgrass (1935) is made up of two sutures, the dorsal part known as the coronal suture and the frontal sutures setting off the frons. The split starts at the coronal suture and continues down both frontal sutures. After the split has reached a point near the antenna it starts to pull the newly formed mandible out of the old mandible skeleton.

Measurements of the head characters follow in Table 4.

Table 4

VARIATION OF THE HEAD CAPSULE OF THIRD
INSTAR *Curculio proboscideus*

Class (mm)	Frequency Head width	Class (mm)	Frequency Head length	Class (mm)	Frequency Mandible length
1.060	-		-		-
1.080	3	.900	1	.390	1
1.100	2	.920	2	.400	5
1.120	2	.940	2	.410	4
1.140	2	.960	2	.420	-
1.160	1	.980	2		
		1.000	1		
		1.120	-		

Class range .10 mm. Class range .12 mm. Class range .03 mm.

From the data in Table 4 it may be noticed that the mandibles vary less than any other character having a class range of .03 mm. The greatest class range is in the head length which is .12 mm.

Fourth Instar. The mature fourth instar larva (Fig. XIV) ranges in length from about nine to 12 mm. and from five to six mm. in width. Measurements for head characters were taken on specimens taken shortly after they had naturally emerged from the nut, and from specimens dug from the soil after they had been in the ground for at least five months. Measurements of the head characters follow in Table 5.

Table 5

VARIATION OF THE HEAD CAPSULE OF FOURTH INSTAR *Curculio proboscideus*

Class (mm)	Frequency Head width	Class (mm)	Frequency Head length	Class (mm)	Frequency Mandible length
1.60	1	1.30	-	.620	-
1.70	2	1.40	2	.640	2
1.80	5	1.50	3	.660	2
1.90	1	1.60	4	.680	0
2.00	1	1.70	1	.700	3
2.10	-	1.80	-	.720	1
				.740	2
				.760	-

Class range .50 mm. Class range .50 mm. Class range .14 mm.

The mature larva comes out of the nut through a circular hole about three mm. in diameter that has been gnawed by the larva. It takes several hours from the beginning of the gnawing until the emergence from the nut. The size of the hole is not always large enough to permit the larva to pass. When this occurs the larva is able to get its head through but cannot move either backwards or forwards nor can it get its mandibles into position to increase the size of the hole. It therefore is a prisoner and dies in this position.

Larvae that have normally emerged from the nut very quickly enter the soil. It is rare for larvae to crawl more than three inches from the point where they first touched the ground. They burrow straight downward with little or no lateral movement for several inches and construct a smooth walled earthen cell. The depth at which these cells are formed varies from two inches to 10 inches. One of the factors which seems to determine the depth of the cells is the nature of the soil. In rocky soil most larvae are found only a few inches below the surface. In soil rich in humus they are found at the depth where the soil layer has a higher concentration of clay. After construction of cells the larvae orient themselves so that their heads are pointed upward. The cell shape is tubular and its size approximately 2½ times the length of the larva, and the width about half again that of the larva.

The fourth instar larva remains in the cell for about nine months and then changes to a pupa. According to Brooks et al (1929) about 10 percent of these larvae carry over the second winter before developing into adults.

The creeping movement of the larvae of both species was observed by placing them on a flat surface. The larva first holds up its head, opens its mandibles and forces the tips into the surface as an anchor. Peristaltic-like movement proceeds from the head to the rear causing the extremity of the abdomen to go forward. Then the contracting waves beginning at the tip of the abdomen lead back to the head, and the process is repeated. The tip of the abdomen is always pressed against the surface. This type of movement is of very unstable character due to an arched condition where the weight is placed on the mandible and abdominal tip and frequently causes the larva to roll over. When the larva was on a rough soil surface little rolling was observed.

To study further the mechanism of the larva entering the soil several larvae of both species were placed on a plot of soil that had been rolled down and made very smooth. It was found that these larvae made no effort to enter the soil unless sticks or pebbles were placed on this surface. When this was done they gained sufficient mechanical advantage to worm their way into soil. When larvae were placed on the undisturbed ground under the trees all of them completely disappeared in the soil within four minutes. These observations suggest that entering the soil is due in part to the contact impulse or thigmotactic orientation.

3. The Pupa. The work on the pupa of both species was limited mostly to a brief description and to characters that differentiated the sexes and species.

The *C. proboscideus* pupa (Fig. XV) is creamy white with blackish brown eyes. As the mature stage is approached brownish markings appear on the body and the wings turn blackish brown. All the rudimentary appendages are compressed against the body except the beak which is held in a bow shape over the venter, and in the female it touches the tip of the abdomen. There is a sparse covering of short hairs over the body; the absence of a pair of these hairs on the beak at the base of the antennae serves to distinguish *C. proboscideus* from *C. auriger*. The pupa is about 15 mm. in length and 7 mm. in width. In this stage there is a distinct difference in the size of what will soon be the male and female.

Pupation occurs in the larval cell about the first of July, and the pupal stage lasts about five weeks. When the pupae are disturbed from the earthen cell they make rather violent movements with the abdomen and when placed in KAAD solution they will spread their wings if they have turned brown.

4. The Adult. Curculio proboscideus is considered to be the largest curculio species in the United States. It is distinct from all other nut weevil species by the antennal structure in which the second funicular segment is longer than the first.

The following technical description is taken from Chittenden (1929).

> Elongate elliptical in outline, body and rostrum piceous, legs and antennae dark brown, vestiture dense, varying from golden yellow or ocherous to gray with or without dark brown spots or fasciae on elytra; squamules very fine and short with the exception of those on the prothorax which are hair like.
>
> Rostrum (female) nearly one-fourth longer than entire body[1], at base sub-parallel with the frons, much thickened, narrowing toward apex; from point of insertion of antennae subuniform in width, nearly straight in the basal half, increasingly arcuate in the apical third, not enlarged at apex. Antennae inserted in front of basal fourth, second funicular joint longer than the first. Mandibles small. Prothorax considerably longer than wide, tubular at apex. Elytra elongate subovate, acuminate at apex, moderately wider than the prothorax. Femora long, strongly clavate and dentate, rentrant angles of teeth strongly obtuse; denticles large and prominent, subacutely produced.

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[1]Measured from the frons to the apex of pygidium.

Last ventral segment broadly and deeply concave at middle.

Rostrum (male) about three-fifths as long as the body, strongly arcuate. Last ventral segment concave at the middle. Pygidium with dense brush of golden hairs.

The length of the female varies from eight to 11 mm., its width from four to five mm. and the length of the rostrum from 12 to 16 mm. The length of the male varies from six to eight mm., its width from 2.5 to 4.0 mm. and the length of the rostrum from six to eight mm. The sexes may be determined by the longer rostrum of the female.

The external taxonomic characters are sufficiently clear for rapid determination of the species, however, many of the species of Curculio are quite difficult to determine.

Since genitalia characters have been very helpful in determining many insect species the male genitalia of the chestnut weevils were studied for taxonomic characters. A survey of the literature revealed only one species of the 39 recognized species of nut weevils with described genitalia.

The male genitalia of C. proboscideus is about five mm. long in the retracted position and consists of a continuous tube with numerous telescoped foldings and extensions. Some parts of the tube are transparent and flexible, while other parts are dark colored and heavily sclerotized. Sharp and Muir (1912) are the source of the terminology.

The copulatory apparatus (Fig.XII) lies under the dorsal integument of the abdomen and averages 5.44 mm. in length. When withdrawn into the body its length is as long as the abdomen with the anterior end attached by muscles to the anterior phragma between the meso and meta thorax. The posterior end is connected to the body just below the anus. The alimentary canal lies largely below but comes above the genital tube caudally.

The median lobe, the most prominent part of the genital tube is heavily sclerotized, deeply colored, with the apical end curved downward and narrowing to a rounded tip. From the proximal end there extends the biforked median strut. Each fork is flattened laterally. These are lighter in color and rather rigid. These parts are covered by a transparent membrane which is divided by the ringlike posterior portion of the tegmen. In the retracted position the tegmen diagonally encircles the median strut near the base of the median lobe and extends back under the median strut as a single process terminating in the basal piece. On the upper surface of the membrane the two arms of the tegmen come together to form the ring.

Under the median lobe and tegmen there is a heavy apodeme about two-thirds the length of the entire copulatory apparatus called the spiculum gastrale. Anteriorally it terminates in a bulb-like thickening joining the basal piece of the tegmen. Posteriorally it terminates in a shoe like thickening called the spicule plate. This structure serves as a guide for the median lobe as it is extended or retracted.

Situated on the dorsal surface near the posterior end of the median lobe there is a tent shaped membrane which has a slit along the top. This structure known as the median orifice or gonotreme serves as the outlet for the sperm.

When the adult emerged from the ground an important factor was observed which was used in the control studies. Instead of immediately flying into the trees they may remain on the ground for a period of more than 24 hours. Forty-five specimens that were reared in the soil cages, none of which was more than two days old, were collected and released in the tree cages. Many of these were observed for two days. Two hours after they were released only two specimens had flown to the tree or side of the cage. These newly emerged specimens were slow to move, and flight was very weak. They may stand motionless on the ground for a half hour or more. They have not been found in the trees before August 8th. They have been observed to fly to the trees to feed and drop back to the ground with no apparent reason. Both sexes fed, on the burrs and kernels, and Brooks (1910) reported finding a male feeding on a Kieffer pear.

The feeding and drilling apparatus in the female is about as long as the body and at its extremity is a pair of mandibles that operate in a scissor like fashion. In piercing a nut the beetle presses the point of the beak against the surface and rotates its body about 180° around the hole. In cross-section the channel is shaped like a half moon. Both males and females feed by piercing the burrs but the male does not often reach the kernel. They also feed to a limited extent on the surface of the burr.

Mating was first observed on August 10th and the latest observation of this act was on August 30th. The egg laying occurs over a period of about five weeks. During the period of August 10th to 30th in the Beltsville orchard 10 large chestnut weevils were found for every small weevil. It is during this time that the greatest activity of the braconid parasite Urosigalphus armatus Ashm. was found.

The female frequently spends several hours performing the operations required for egg laying. When the drilling has been completed she withdraws her beak, turns deliberately around and then, after inserting her long telescoped ovipositor, which is almost as long as the rostrum, lays a single egg at the bottom of the hole. A number of punctures each containing one egg may thus be laid on a single burr. According to an unpublished report of Van Leeuwen C. proboscideus females may lay from 25 to 50 eggs.

There is little beetle activity on cool or damp days and shaking the tree rarely produces any beetles. They are rather sluggish in their movements and easily caught. When crawling over a burr or foliage they drop to the ground when disturbed and make no effort to fly. When the female is drilling a hole she is difficult to disturb. She may even be touched without any effort to free herself from the nut and escape danger.

5. Resume of the Life Cycle. *Curculio proboscideus* lays its eggs in late August and they hatch in ten days. The larvae develop within the nut in 30 days. Soon after maturity the larvae issue from the nut and burrow into the ground to a depth of about four inches. Here they construct earthen cells where they remain as larvae until the following spring. A few larvae remain in the earthen cell over two winters. In July they pupate and begin to emerge from the soil as adults about the first of August.

The adults remain on the ground surface or litter for several days then fly to the trees. Frequently the adults drop back to the ground for a short period of time. Mating occurs in the trees during early August and egg laying follows shortly thereafter. The usual cycle lasts about one year. A few individuals require two years.

CHAPTER VII

CURCULIO AURIGER (CASEY)--DESCRIPTIONS AND OBSERVATIONS

1. The Egg. The egg of Curculio auriger (Fig.XIII) is oval in shape and measures about 0.4 by .7 mm. It is pellucid white until a day or two before hatching when the chorion becomes sufficiently clear to observe the developing larva. When the eggs are placed in alcohol the chorion of the eggs in all stages become clear enough to observe the developing embryo. The eggs are laid deep in the kernel and require about eight days for hatching. They may be separated from C. proboscideus eggs by their smaller size and frequently by their shape. From the main stem of the puncture there are several side branches (Fig. IX). As many as six branches have been found each containing an egg. The galleries are quite small and sometimes difficult to follow. There is no necrotic tissue along the galleries or at the point where the egg is located.

2. The Larva. The mature larva of Curculio auriger is very much like that of C. proboscideus. C. auriger can be separated from C. proboscideus by its smaller size, by the presence of distinct adfrontal areas near the fork of the epicranial suture and by the mandibles which have shorter

teeth and the inner arch is not as rounded. The mandibles offer good taxonomic characters even though they may be badly eroded after they have cut through the nut shell. The number of instars of both species was determined by finding the moulted head capsules, by head measurements and was further corroborated by applying Dyars' (1890) law to the measurements.

The time elapsed in each of the four instars is difficult to observe therefore an indirect method was used for estimating the period of time required for each stage. This method involved the collection of all stages in the nut over the entire growth period.

Twenty burrs were collected each day or every other day starting August 11, 1955. The first eight collections were taken daily thereafter about every other day. When it was not possible to take the immature forms from the nuts immediately after collecting, they were placed under refrigeration at about 38° F. and inspected later. Due to mechanical failure of the refrigeration equipment the collections from several days were lost. With the existing data an estimate of the periods of time necessary for each growing stage of both species was made. A graphic representation is found in Figure I .

At the beginning of the oviposition period only a few eggs can be collected, but in the course of time this number increases and the height of the oviposition period can be plotted. The most numerous larvae of the first instar are

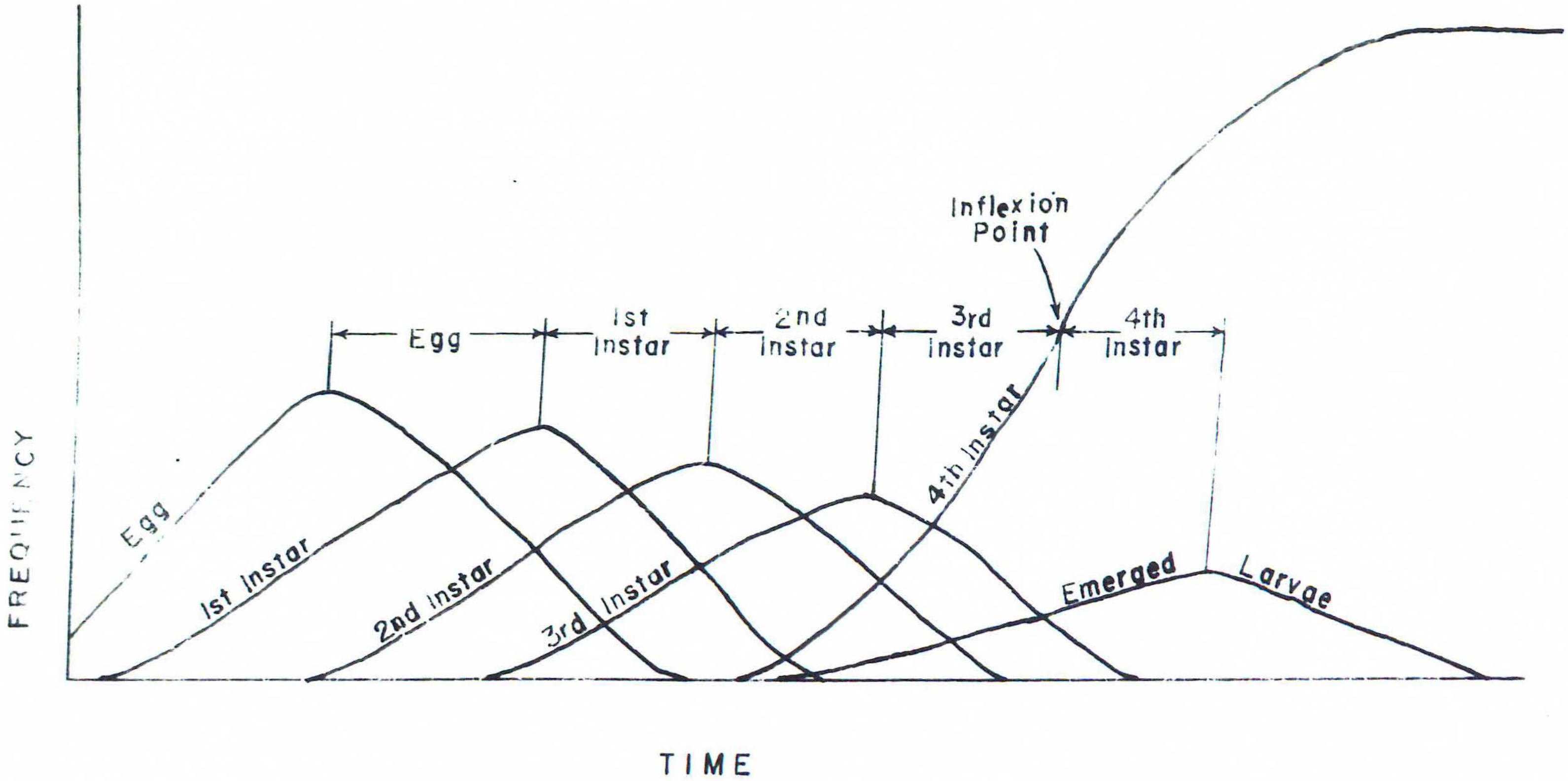


Figure I. A diagram showing the method used to determine the egg stage period and the periods of the four instars.

to be found when the majority of first instar larvae hatch from the egg. Consequently the decreasing of the number of larvae in the earlier stages is accompanied by the increasing of those in the succeeding stages.

Therefore, the time between the day when the maximum number of eggs was collected and the day when the first instar was most numerously collected is the period of the egg stage. It will also be recognized that the time of the maximum number of the first instar to that of the second instar is the period of the first larval stage. The second instar can similarly be calculated. To determine the third instar one must first investigate the fourth instar. First of all the number of the fourth instar larva accumulates everyday since no other moult occurs and plotted, frequency against time, on a graph it forms an S-shaped curve. If we use the inflexion point which by definition is the point where the curvature of convex to concave takes place then we can determine the period of the third instar. From the inflexion point to the peak of larval emergence will be the period of the fourth instar.

Accordingly the period of the egg and each instar was estimated as follows:

Egg stage	8 days
First instar	6 days
Second instar	5 days (approx.)
Third instar	4 days (approx.)
Four instar (before emergence)	6 days

Larval development occurs over a period of about 21 days although many do not emerge when development is completed.

They have been found to remain in the nut for over a week after cutting their emergence holes.

Emergence records from 50 infested nuts collected on September 19th show that the first C. auriger larva emerged on September 22nd. The greatest number emerged on October 12th and the last larva emerged on November 1st. In the field the last recorded larval emergence was November 18, 1955.

First Instar. The first instar larva is about one mm. long. Its head like that of C. proboscideus is large in proportion to the rest of the body. None of the abdominal stigmata are visible when magnified 160 times. This instar feeds in a straight line and a moult takes place after it has fed over a distance of about eight mm. The point where the moult took place can be determined by an enlargement of the tunnel.

Table 6 shows the measurements of certain head capsule characters.

Table 6

VARIATIONS OF THE HEAD CAPSULE OF FIRST INSTAR

Curculio auriger

Class (mm)	Frequency Head width	Class (mm.)	Frequency Head length	Class (mm.)	Frequency Mandible length
.280	-	.200	-	.090	1
.300	1	.220	1	.100	4
.320	8	.240	8	.110	3
.340	-	.260	-	.120	2
.360	1	.280	1	.130	-

Class range .08 mm. Class range .08 mm. Class range .04 mm.

There is a greater range within each instar of C. auriger as compared to C. proboscideus but the difference between instars is sufficiently great to determine the instar number.

The stemmata in this instar has not been found and the adfrontal areas cannot be differentiated.

Second Instar. In the second instar small dark pigmented spots may be found near the antennae and are believed to be the stemmata. The adfrontal areas have begun to form and the head is still proportionally larger than the rest of the body. The total length of the body is variable but averages about three mm.

Measurements of certain head capsule characters follow in Table 7.

Table 7

VARIATIONS OF THE HEAD CAPSULE OF SECOND INSTAR

Curculio auriger

Class (mm.)	Frequency Head width	Class (mm.)	Frequency Head length	Class (mm.)	Frequency Mandible length
.660	-	.480	-		
.670	2	.500	1	.220	2
.680	4	.520	1	.230	3
.690	4	.540	2	.240	4
		.560	6	.250	1

Class range .03 mm. Class range .08 mm. Class range .03 mm.

Third Instar. The third instar has most of the characters of the fourth instar. Most of the head bristles are present, and also a pair are found on the mandibles.

A second pair of dark pigment spots make their appearance a short distance above the stemmata which are thought to be sensory spots.

The adfrontal areas are well formed.

Measurements of the head characters follow in Table 8.

Table 8

VARIATIONS OF THE HEAD CAPSULE OF THIRD INSTAR

Curculio auriger

Class (mm.)	Frequency Head width	Class (mm.)	Frequency Head length	Class (mm.)	Frequency Mandible length
.960	-	.780	2		
.970	2	.800	2	.380	2
.980	1	.820	1	.390	2
.990	3	.840	3	.400	4
1.000	3	.860	1	.410	2
1.010	1	.880	1	.420	-
Class range .05 mm.		Class range .10 mm.		Class range .04 mm.	

Fourth Instar. The mature larva of this species closely resembles C. proboscideus in nearly every respect. It is shorter in length and more slender in form. The full grown larva ranges in length from seven mm. to 9.5 mm. The vertex of the head is covered by a fold of the prothorax. The measurements in Table 9 were taken from specimens not yet emerged from the nuts and from specimens taken from the ground after they had been in the pupal cell for more than five months.

Table 9

VARIATIONS OF THE HEAD CAPSULE OF FOURTH INSTAR

Curculio auriger

Class (mm.)	Frequency Head width	Class (mm.)	Frequency Head length	Class (mm.)	Frequency Mandible length
1.20	1	1.00	1	.510	1
1.25	1	1.05	3	.520	0
1.30	5	1.10	2	.530	3
1.35	2	1.15	3	.540	3
1.40	1	1.20	1	.560	1
				.570	0
				.580	2

Class range .20 mm. Class range .20 mm. Class range .06 mm.

Mature C. auriger larvae emerge from nuts by cutting a circular hole about two mm. in diameter. They enter the soil in the same manner as described for C. proboscideus larvae. Most of the larvae are found in earthen cells at a depth of two to eight inches. Van Leeuwen (1952) reports that 97 percent are found in the first eight inches of soil. These larvae remain in their cells for a period of about 11 months before pupating. Occasionally the larvae may remain in their cells over two winters or about 23 months before pupating. The maximum number of larvae found to emerge from a single nut was 26 specimens. Not all larvae make their own exit holes. Van Leeuwen (1952) reported 58 larvae from a single Japanese chestnut.

3. The Pupa. The pupa of C. auriger (Fig. XV) is white in its early stage and turns blackish brown color as it approaches maturity. All the appendages such as the

antennae, beak, legs and wings are distinct and are compressed against the body with the exception of the beak. The beak is curved away from the venter and in the female touches the tip of the abdomen with the scissor like mandibles at its terminus. The pupa that are soon to be males and females may be distinguished by the smaller size of the immature male. The presence of a pair of short hairs on the upper surface of the snout at the insertion of the antennae in C. auriger serves to separate this species from C. proboscideus.

Pupation starts about the first of September and adults may be found in the earthen cells near the last of September. All have changed to the adult by the middle of October. The pupal stage lasts from two to three weeks. There are a number of bristles along the dorsum of the head, thorax and abdomen as well as on the legs. No bristles are on venter of abdomen. The front and middle legs are folded over the wing pads, the hind wings beneath the pads. The elbow of the antennae reaches the eye.

As the pupa approaches maturity the tarsal claws and mandibles darken and appear like those of the adult. The hind wings extend beyond the elytra by about 0.8 mm. The flight reflex is stimulated when the pupa is placed in KAAD solution.

Length of the pupa varies from six mm. to nine mm. and it is about 3.5 mm. in width.

4. The Adult. Curculio auriger, or the small chestnut weevil (Fig. XVII) in all its stages bears a close resemblance to the larger species, but it markedly differs from it in its life cycle.

They are from five to nine mm. in length and from 2.5 to 3.5 mm. in width. The female rostrum measures from five to nine mm. and the male from 2.5 to 3.5 mm. This character makes it easy to identify the males and females.

The following technical description is taken from Chittenden (1929).

> Slender, convex; piceous-black, antennae and legs rufopiceous to pale red. Vestiture dense, variegated golden yellow; scales fine and short, hair-like on the prothorax with a wide dark brown area each side of the middle of the prothorax and with smaller, irregular, dark brown, subtransverse fasciae on the elytra.
>
> Rostrum female usually distinctly longer than the body, slender, subparallel with the frons, moderately enlarged at the base, scarcely at the apex; strongly and nearly uniformly but somewhat variably arcuate. Antennae inserted behind the basal third; scape longer than the succeeding three funicular joints together, 1 one-third longer than 2, 2 slightly longer than 3. Prothorax a little longer than wide. Femora moderately clavate and somewhat feebly dentate, with denticles large and strongly produced; reentrant angles obtusely rounded. Fifth ventral segment very widely and deeply concave.
>
> Rostrum male about half as long as the body, thicker than in female, strongly arcuate, much enlarged at base. Femoral tooth less strongly developed than in female. Antennae inserted about at, or just in front of, the middle. Last three ventral segments gradually ascending, the fifth narrow.

It should be pointed out that the "piceous-black" color of the body refers to a specimen devoid of scales or hairs. These scales give the body color. Specimens collected early in the season have the "variegated golden color," those collected late in the season and especially females, will appear more black than gold, depending upon the number of scales that have been rubbed off.

Briefly they may be separated from C. proboscideus by smaller size, more slender form, shorter and greater curvature of the beak and in life by their quicker movements. They are easily alarmed when feeding or laying eggs and at the slightest alarm they will fly, hide in the spines of the burr or drop to the ground feigning death.

The phallus (Fig.XVIII)was also studied in this species for taxonomic characters. It is much like that of C. proboscideus differing in size and especially in the shape of the median lobe at its terminus. The median orifice is not as pronounced as in C. proboscideus and the median lobe is bulb-shaped with greater curvature at its terminus. The average length in the retracted position is 3.7 mm. All genital structures described in C. proboscideus are found in C. auriger.

The pupa changes to an adult during September and does not begin emerging from the soil until the first of May. The emergence data over a two year period show May 5th to be the earliest date that this species was found in rearing cages. The latest date of emergence was June 16th. This essentially corroborates Van Leeuwen's (1952) findings.

Therefore, there is a period of about 41 days in which emergence takes place.

When specimens first emerge they crawl fairly actively over the soil and litter and prefer dark or protected places. They are believed to remain on the ground or turf for a period of several days. They fly to the chestnut catkins and feed on the male flowers. They rarely remain on the catkin for more than a half hour at a time, then fly or drop back to the ground. After the catkins have withered the weevils disappear. They have not been found in the trees again until about the time of oviposition. This species has a preoviposition period of about four months.

Mating was frequently observed in the trees starting about August 17th and last observed on October 5th.

Eggs have been found as early as August 26th but most of the eggs are laid after the burr begins to open. C. auriger feeds and drills holes in much the same manner as C. proboscideus. Both males and females have been observed with their beaks piercing nuts that have fallen on the ground. Males are often found feeding on fuzzy moist inner lining of the burr. Frequently, the head and the beak are found broken off with the beak still buried in the nut. This is probably due to birds striking at the weevil while it is drilling a hole. Occasionally a specimen was found dead on a nut attached only by its imbedded beak.

There are several reports that C. auriger breeds only in the fruits of chestnut and chinquapin. No records have been found showing any attempt to force oviposition in other nuts. Therefore an experiment was conducted to determine whether _C. auriger_ could be forced to oviposit in white oak acorns. Two rectangular cages 12 x 12 x 24 inches were constructed which would slip over a branch containing a cluster of nuts. The sides were covered with plastic screen and the ends were covered with a long cloth sleeve.

One cage was placed in an oak tree and another in a chestnut tree. Before each cage was tied in place the nut clusters were examined for weevil punctures and any nut or burr showing evidence of punctures was removed; then six females and three males were introduced to each cage and the sleeves tied securely.

The results of this experiment showed no evidence of _C. auriger_ feeding or laying eggs in the acorns. All the specimens with the acorns died within 10 days. In the cage containing the chestnut burr, feeding and egg laying punctures were observed. Four larvae were found in a single nut. In seven days all the males were dead and all females were dead in two weeks.

Under the conditions of this experiment it can be concluded that _C. auriger_ will not lay its eggs in white oak acorns and that the cage affects oviposition on chestnuts.

5. Resume of the Life Cycle. _Curculio auriger_ lays its eggs in September. The eggs hatch in about eight days.

The larvae develop within the nut in about 21 days. Soon after it is full grown the larvae issue from the nut and burrow into the ground to a depth of about six inches. Here they construct an earthen cell where they remain as larvae until September of the following year at which time they pupate. They remain in the pupal stage for about four weeks and then change to adults. The adults remain in the earthen cell over the second winter and emerge from the ground in June, about 21 months after they entered the soil as larvae. A few larvae remain in their earthen cells over two winters and change to pupae and adults in the same sequence and time interval as the other individuals. When larvae remain in the earthen cell over two winters the underground period lasts for about 33 months.

Upon emergence from the ground the adults crawl over the ground surface for a few days, then intermittently fly back and forth, from the ground to the trees to feed on the chestnut catkins.

After the catkins wither the beetles disperse and are not found in the trees again until the middle of August. Mating occurs in the trees in August and egg laying takes place shortly thereafter. The usual cycle lasts two years. A few individuals require three years to complete their life cycle.

CHAPTER IX

NATURAL ENEMIES

In his work done in West Virginia, Brooks (1910) reported four species of internal parasites of nut weevil larvae. *Urosigalphus armatus* Ashm., and *Sigalphus curculionis* Fitch, both braconids, were reared from both species of chestnut weevils. Also two tachinids were found, *Myiophasia aenea* (Wied.) and *Cholomyia inaequipes* Bigot.[1] Brooks and Cotton (1929) reported two additional tachinid parasites, *Winthemia quadripustulata* Fab. and *Myiophasia nigrifrons* Tns.

Urosigalphus armatus and *Myiophasia nigrifrons* are the only insect parasites of chestnut weevils found in these studies. They have been found in only three orchards and in no instance could they be considered numerous enough to be a major control factor.

From soil cages, where approximately three thousand larvae were being reared, only 32 *U. armatus* emerged in 1955. Of the 32 specimens approximately half were males and half females. Their emergence in the soil cages coincides very closely to that of *C. proboscideus* emergence and occurs over

[1]Brooks called this species *Metadixia basalis* G-T which has since been made a synonym.

a period of 28 days.

Table 10

EMERGENCE RECORDS OF *Urosigalphus armatus*

Male	Female	Date
3 specimen		8/8/1955
3 specimen		8/11/1955
2	2	8/16/1955
2	1	8/18/1955
4	5	8/20/1955
3	3	8/25/1955
2	2	9/4/1955

Urosigalphus armatus (Fig.XIX) is a braconid wasp from six to eight mm. long. The ovipositor is from 10 to 12 mm. long which is about the same length as the beak of the female *C. proboscideus*. The head, thorax, and abdomen are metallic black, eyes dark and the antenna black. The legs and maxillae are rufus in color with the exception of the third pair of legs on which the tibia and tarsus are black.

Where present in an orchard they are easily recognized and are often seen flying about the chestnut trees and crawling upon the burrs. The female has been observed several times searching for the beetle puncture and laying eggs. After the oviposition hole of a nut weevil has been located she straddles the hole, standing with the rear legs nearest the hole, raises her abdomen high in the air and with some difficulty finds the hole with the tip of the ovipositor. The process of egg laying takes about two minutes from the insertion of the ovipositor until it is withdrawn. During this time the only movement made is by the antennae and the abdomen. The time of activity of the wasp seems to vary. Some days they may be seen during all day light hours; other days they are seen only during the morning.

There seems to be a preference for the larvae of C. proboscideus. They emerge from the ground about the same time and disappear about September 15th which is 13 days after the oviposition peak of C. proboscideus. No immature U. armatus have been found in the body cavity of C. auriger. Brooks (1910) writes that U. armatus "seems especially fond of the larger chestnut weevil."

From the three rearing cages previously mentioned 82 specimens of Myiophasia nigrifrons (Fig.XIX) emerged. Twenty-four of these were males and 58 females. Emergences began on September 11, 1955 and continued through October 8, 1955 for a period of 28 days. The early emergence records showed a much larger number of males than females and the males decreased in number in each subsequent collection. Of the total number of specimens there were twice as many females as males.

Table 11

Emergence Records of Myiophasia nigrifrons

Male	Female	Date
2	0	9/9/1955
10	2	9/14/1955
5	11	9/20/1955
5	15	9/30/1955
2	21	10/5/1955
0	6	10/7/1955
0	3	10/10/1955
24	58	

Myiophasia nigrifrons is a metallic black tachinid fly with orange eyes and rufus yellow cheeks which retain the color in alcohol but not if specimens are dried. Their size is quite variable. The males are generally smaller (five mm. to nine mm.) than the females but males have been found as large as the largest of female specimens. Females do not vary as greatly in size and range between seven to nine mm. These females compare in size to *Phaenicia sericata* *Meigen*, one of the green bottle flies.

In the orchard these flies are found flying around the trees and crawling on the burrs and leaves. Mating has been observed to occur on the burrs. Since many of the tachinids are larviparous, an effort was made to find larvae on the burrs. Very small dipterous larvae were found on burrs that had cracked open. These larvae were not definitely determined and there is insufficient evidence to prove that they were immature *Myiophasia nigrifrons*.

One female specimen was dissected to determine the number of eggs. Five hundred and twelve eggs were found. No larvae were present.

An experiment was conducted to determine whether *Myiophasia nigrifrons* would oviposit or larviposit on mature curculio larvae in a confined space. A cage 12 x 12 x 12 inches covered with 16 mesh screen on the sides and top was used. The back was a 12" wood panel and the front a piece of removable glass. Nuts containing both species of weevil larvae were placed in the cage for normal larval emergence from the nuts. Six *M. nigrifrons* flies were then introduced (two males and four females). Over a period of three days nine larvae emerged, two of which were *C. proboscideus*. The larvae were removed from the cage every 24 hours and observed for eggs or larvae on the cuticle. They were then placed in a soil cage for normal development. No parasite eggs or larvae were observed on the cuticle. In May, 1956 these specimens were retrieved and dissected. None were found parasitized.

These two internal parasites have been found in three Maryland orchards located at Beltsville, Glenn Dale and Blythdale. At the Beltsville orchard they cannot be considered a major factor in chestnut weevil control due to the comparatively small number of parasites versus adult weevils to emerge from soil cages.

Two insectivorus mammals are important enemies of nut weevils. The short tailed shrew *Blarina brevicauda* Say and the common ground mole *Scalopus aquaticus* (L.) have been trapped at the Beltsville orchard. In the late fall and early spring their tunnels are so numerous under the trees that a step can scarcely be taken without sinking into them. Brooks (1908) states that where these hunters are numerous not more than 10 percent of the larvae that enter the ground in the fall can be found the following spring. Brooks also states that he saw a shrew devour 72 large chestnut weevil larvae in less than five minutes and according to Cahalane (1947) a shrew can eat its weight in meat in three hours.

The meadow mouse *Microtus sp.* according to Brooks (1908) will also feed on the larvae and adults of chestnut weevils as well as many other insects when placed in a cage with the mouse.

The meadow mouse was not trapped at the Beltsville orchard but a fairly large population of pine mice *Pitymys pinetorum* (LeConte) was found. These mice according to Cahalane (1947) make tunnels and feed on insect larvae in addition to feeding on vegetable material.

Davis (1907) describes seeing gray squirrels *Sciurus sp.* eating curculio larvae from acorns. On the campus of the University of Maryland tame squirrels *Sciurus sp.* were given a choice of sound nuts and those with weevils. In every instance the nuts with weevils were refused even when all the sound nuts had been taken.

Birds have also been observed to feed on nut weevils. In 1937 A. L. Nelson of the Bureau of Biological Survey U.S.D.A. listed, in a personal communication to G. F. Gravatt, 84 birds that had been found to have species of *Curculio* in their stomachs or digestive tracts. From this list only the night hawk, bluebird and red-eyed vireo were found to have definitely fed upon *C. proboscideus*. In the Biological Survey's records *Curculio sp.* were found most frequently in the digestive tracts of the flycatchers, swallows, scarlet tanagers, vireos, blackbirds, red-headed woodpeckers and titmice.

Although pathogenic fungi have been found to control certain other nut weevil larvae (Swingle et al 1931) no fungi have been found on chestnut weevil larvae. Chestnut weevil larvae dug from soil that is wet and poorly drained have frequently been found to have dark spots of various shapes and sizes on the cuticle. The cause for these discolorations has not been determined.

CHAPTER X

CONTROL METHODS

1. Physical Controls. The earliest control methods depended upon physical or mechanical methods. A survey of the literature and Department of Agriculture records showed that the earliest work on this phase of control was done by W. B. Wood with the U.S.D.A. In 1916 he reported an attempt to control the larvae and eggs in nuts by hot air varying from 120° to 130° F. for a period of two hours. These treatments were unsuccessful, for the nuts soon became unfit for use when placed in storage.

In 1917 W. B. Whitcomb tried cold treatments ranging from 0° to 32° F. over a period of 10 days to two weeks. Only those temperatures of 20° or lower killed larvae. These experiments were considered unsuccessful from a practical standpoint because low temperatures also have a deleterious effect on the nuts rendering them inedible a few days after treatment.

Hot water treatments have been described from several sources but the quality of the nut deteriorates after such treatment.

Prior to contact insecticides the daily harvest of nuts was recommended and destroying the larvae as they issued from the nut. Also it was found that shallow plowing under the trees was helpful especially if done in the spring. Also frequent jarring of the trees has been recommended to collect adult beetles on a sheet or canvas spread under the trees.

Nichols et al. (1947) described the effect of flooding on pecan weevil larvae in the ground. This work shows some possibilities for chestnut weevil control if irrigation equipment is available and the physical characteristics of the land are suitable. In some of the metal containers used for rearing chestnut weevils drainage through the bottom of the can was slow enough to kill all the larvae therein.

2. Chemical Controls. The first control methods by chemical means was by the use of fumigants, particularly carbon disulfide. This method of control is quite successful for controlling larvae and eggs in the nut and is still being used today. All nuts being shipped out of the country must be fumigated prior to shipment.

Brooks et al. (1929) wrote of chestnut growers either spraying or dusting with arsenicals and describes one of the early spray mixtures for weevil control. This mixture contained one gallon of lead arsenate, one gallon of sirup, and three pounds of lime in 50 gallons of water. Brooks concludes that spraying with arsenicals does not reduce the curculio population more than 50 percent.

In 1949 Van Leeuwen first published on the control of weevils with DDT and this work is the basis for the present U.S.D.A. spray schedule. This recommendation calls for three applications of a DDT spray applied at weekly intervals starting about the 15th of August. The spray is prepared by mixing four pounds of 50% wettable powder in 100 gallons of water.

This spray schedule, when rigidly adhered to will give satisfactory control but requires high pressure equipment and large quantities of water. The recommendation calls for one gallon of spray for each foot of tree height. A miticide must be added to this spray to control two species of foliage mites, Eotetranychus hicoriae (McGregor) and Oligonychus bicolor (Banks). The Department of Agriculture suggests 15 percent Aramite wettable powder or 25 percent malathion wettable powder at the rate of two pounds per 100 gallons of water for controlling these mites. One application is usually enough.

Van Leeuwen (1953) published on his work with fumigants and insecticides for larval control in the soil. He concluded that ethylene dibromide was the best of three other fumigants tested and that Toxaphene, chlordane and parathion when worked into the soil were not effective against the larva. Van Leeuwen was unable to investigate soil poisons further, and the control experiments represented in this thesis are attempts to continue the work where he stopped.

The most vulnerable period in the existence of the larva is at the time it leaves the nut to burrow into the soil. Before that time it is hidden within the nut and afterwards it is inclosed within a cell below the surface of the ground. Although the time consumed by the larva in entering the soil is comparatively short it is a critical period because of exposure to which the larva is subjected. Following some of the thoughts and suggestions given by Dr. Van Leeuwen the work on soil poisons was continued by making a series of insecticide screening tests to determine what insecticides merited further study. Treatments were made in eight plots, three feet square, in the Beltsville orchard. The leaves and debris were cleared from each plot and the vegetation cut to about two inches. One plot was used for each treatment. One-half gallon of an insecticide solution was poured on each plot with a garden sprinkling can. After 24 hours two pounds of infested nuts were placed at the center of the plot and the entire plot covered with a screened cage. It was estimated that at least 75 larvae were subjected to each test. Mortality records were taken on the fifth and fourteenth day after exposure. The results (Table 12) show no promising treatments.

Table 12

RESULTS OF FIELD SCREENING TESTS FOR CONTROLLING CHESTNUT WEEVIL LARVAE AS THEY EMERGE FROM THE NUTS

Chemical	Dosage Rate In Pounds Per Acre	Mortality 14 days after treatment
Chlordane wettable powder	8 lbs.	0
Cyanamid*	1200 lbs.	0
DDT emulsion	8 lbs.	0
DDT wettable powder	8 lbs.	0
Dieldrin wettable powder	8 lbs.	0
Heptachlor wettable powder	8 lbs.	2
Lindane Paradichloro-benzene emulsion	5 lbs.; 32 lbs.	13
Check	----	0

* High nitrogen fertilizer

The lindane paradichlorobenzene treatment gave the best results. The larvae that were killed on this plot were all found on the surface or within the first inch of soil. Larvae that had made their way through the insecticide barrier were apparently in a healthy condition. While this experiment was in progress a field trial was made in August in an orchard of Japanese chestnut trees near Betterton, Maryland. Before treatment the ground under the tree was raked and disced. Ten percent DDT dust was applied with a fertilizer spreader at the rate of 24 pounds actual per acre. After four weeks results were checked by inspecting one cubic foot of soil in each of ten plots.

The results showed no dead larvae but numerous live and healthy ones. This orchard was not visited again until August of the following year and both species of weevils were numerous in the trees indicating that the DDT in the soil did not control adults. Later the crop was estimated to be 95% infested with weevil larvae. With negative results no further tests were made to control the larval stage.

Van Leeuwen's work in 1949 had already established the value of DDT for controlling both species of adult curculios. With this fact in mind a series of tests on the adults of C. auriger were conducted to determine the effectiveness of several organic insecticides known for their effective residues on other insects. A wooden panel six inches square was dipped into a 3% wettable powder suspensions of either DDT, heptachlor or dieldrin. The panels were allowed to dry and ten weevils were exposed to each panel. The beetles were released at the center of the panel and they walked over at least three inches of the treated surface. All test specimens were females and approximately the same age. After treatment those insects that were exposed to DDT were kept in separate holding cages as well as those treated with heptachlor and dieldrin. All holding cages contained a small chestnut branch carrying a single burr in a beaker of water and were placed under a tree in the Beltsville orchard. Results of the tests were taken at one hour and 24 hours after exposure. There was no mortality at one hour but the insects in all treatments were dead in 12 hours. All the weevils in the check cage were alive.

After observing that both species of adult chestnut weevils remain on the ground for some time after emergence from the soil and that they frequently fly, or drop back to the ground it was decided that insecticide treatments to the soil surface might give successful control.

In the spring of 1955 field tests were conducted in two private orchards. Each of these orchards had made good yields during the previous two years and each year the nuts were badly infested with weevils. Planting "A" was nine years old and contained 12 trees planted in a single row bordering a peach orchard. Planting "B" was operated as an orchard and contained 33 trees about 14 years old. Planting "A" was treated twice with heptachlor wettable powder at the rate of six pounds of actual chemical per acre in 50 gallons of water.

The spray was applied to the ground with a boom type sprayer using Tee-Jet nozzles number 6503 and spaced 20 inches apart on the boom. The boom was placed about 20 inches above the ground and the grass under the trees was cut to about three inches. A treatment was made on May 20th and July 29th.

The results from this experiment exceeded all expectations. Sixty pounds of nuts were harvested and not a single weevil or exit hole in a nut was found.

Planting "B" was treated once on June 6th. Heptachlor dust was applied with a hand fertilizer spreader using eight pounds actual per acre. Results from this treatment also exceeded expectations. From a harvested crop of 700 pounds no weevil larvae were found although one female <u>C. auriger</u> was found in the orchard in August.

CHAPTER XI

SUMMARY

The chestnut weevils, *Curculio auriger* and *Curculio proboscideus* are the most serious insect pests of chestnuts. They lay their eggs in the fruits of chestnut and chinquapin, and the developing larvae make the nuts unfit for use.

Both species are easy to rear in the field and this was accomplished by the use of soil cages set into the ground to a depth of 12 inches.

Since the destruction of most of the native chestnut trees by blight the weevils have survived on the nuts of chinquapins, scattered plantings of oriental chestnuts resistant to blight, and on native chestnuts that have survived the blight either by being resistant or from the coppice growth of old stumps. The natural distribution of these weevils occurs over the same areas that American chestnuts were found.

The two species closely resemble each other in all stages but there are taxonomic characters that will separate each stage. The two curculios markedly differ in their life cycles. *Curculio auriger* normally completes its cycle in two years but occasionally it requires three years. *Curculio proboscideus* usually completes its cycle in one year but a few individuals carry over to the second year.

The larva goes through three moults and four instars. These were determined by head measurements, by finding the moulted head capsule and further corroborated by the application of Dyar's law.

The pupa of both species are of the exarate type and require about five weeks to complete this stage.

The male genitalia were described and illustrated and were found to have valuable taxonomic characters.

These nut weevils have several parasites and predators. The most important parasites are the braconid wasp, Urosigalphus armatus and the tachinid fly, Myiophasia nigrifrons. Two insectiviores, the short tailed shrew and the common ground mole are the most important mammalian predators and reduce the larval population in the soil to a great degree.

Observations on adult behavior led to successful chemical control measures. Two applications of heptachlor applied to the ground surface about four weeks apart gave 100% control.

APPENDIX

OTHER INSECTS ATTACKING CHESTNUT FOLIAGE AND FRUITS

In this study several other insects and mites were found feeding either on the foliage, the burrs or nuts. Those will be discussed briefly in order of economic importance.

Since about 1953 *Cyrtepistomus castaneus* (Roelofs), the Asiatic oak weevil, has been causing varying degrees of damage to chestnut foliage. This weevil was introduced from Japan and first reported in Maryland in 1949. Triplehorn (1954) worked out its life cycle. The adult weevils are leaf feeders and the larvae are presumably root feeders. Young saplings and branches close to the ground begin to show damage first. This generally occurs in early August. The number of weevils increase as the season progresses and by the middle of September damage is quite obvious even in the topmost branches of the tree. The leaf damage to all species of trees observed had followed the same typical pattern. All the leaf tissue was eaten away leaving only the mid-vein and its lateral branches. With Chinese and hybrid chestnut trees, growing under forest conditions, it was not uncommon to see as much as 35% defoliation. In some unsprayed orchards damage frequently reached the same level. Very young trees were practically defoliated. Where orchards or young nursery stock were growing near to oak forests or wood lots, damage was always greater to chestnut trees than to the oaks. From several observations of these conditions it is believed that chestnut and chinquapin are the choice host plants. The pest has been observed to feed more frequently on the leaves of species of oak, beech and hickory because of the scarcity of chestnuts. Triplehorn (1954) lists 34 species of plants on which these beetles will feed. There is considerable feeding on the green chestnut burr but the extent of damage has not been ascertained. In several unsprayed orchards it was not uncommon to find from six to a dozen of these weevils feeding or hiding between the spines of each burr.

A measure of control on this insect results from the foliage sprays for the large and small chestnut weevils, *Curculio proboscideus* Fab. and *C. auriger* (Casey). The Asiatic oak weevil is easy to kill by wettable DDT sprays, and oil fogs containing DDT or lindane. The greatest difficulty occurs in areas where the trees are in close proximity to oak wood lots, for reinfestation occurs rapidly after the residue wears off.

There are two species of spider mites that frequently cause damage to chestnut foliage on the east coast. *Oligonychus bicolor* (Banks) is the most important species and has been found feeding on the upper surface of the leaf and occasionally on the bark of young twigs. Where found they are in large numbers. Eggs are laid along the mid-rib and lateral veins. They are barrel shaped and rather squatty and adhere very strongly to the upper leaf surface.

On the leaf the mite has a readily recognizable color pattern. The legs and anterior third of the body are salmon-orange in color with a narrow yellow transverse band along posterior dorsum. The rest of the dorsum is bay brown. Color soon leaves specimens preserved in alcohol.

The damage is manifested by leaf discoloration along the veins. Leaves turn cinnamon-drab along the veins and later take on a grayish-olive color, due in part to the webs and moult skins.

Oligonychus bicolor is fairly common and is likely to be found all along the east coast. Phillip Garman (1923) wrote that this mite is most common on oak and is also found on chestnut and birch.

Eotetranychus hicoriae (McGregor) has been reported by Van Leeuwen in a personal communication to cause sporadic damage in Maryland. The writer has not found this mite. Its host plants are reported (Pritchard and Baker 1955) to be hickory, oak, buckeye, pecan and chestnut.

Mnemonica auricyania (Wlsm.) is a small moth in the family Eriocraniidae. Its larva is a leaf miner causing damage to chestnut foliage in the spring. The extent of damage is not great, at the present, but is increasing under orchard conditions each year. The mine often begins as a gallery, but soon expands to a blotch which may not involve the part of the leaf where the gallery was at first. The early part of the mine is often obliterated, making a fissure in the growing leaf. Infested leaves may often be located by this fissure. The blotch becomes big and swollen and often covers a quarter or more of the leaf's total area. The entire parenchyma is eaten out and the mine is equally visible from either side and so translucent that one may easily see the larvae and the black frass which is deposited in long irregular curled threads. The full grown larva is nine to 10 mm. in length, whitish in color and flattened. It is mature in about 10 days. It then cuts a small semi-circular slit in the upper epidermis of the leaf and drops to the ground where it completes its life cycle.

The moths are first seen the last of April and their flight is weak and irregular. The attack by larvae on the foliage is short lived and important only in early spring.

Two other species of mites *Glycyphagus domesticus* (Deg.) and an undetermined species in the genus *Tydeus* have been found associated with nuts and burrs that have dropped to the ground. These mites are numerous if they are protected by dense shade.

Other species found associated with foliage are the aphid *Longistigma caryae* (Harris) and *Stephanitis rhododendri* Horvath in the family Tingidae.

The nitiduled Carpophilus lugubris Murr is frequently found in burrs and on nuts that have dropped to the ground.

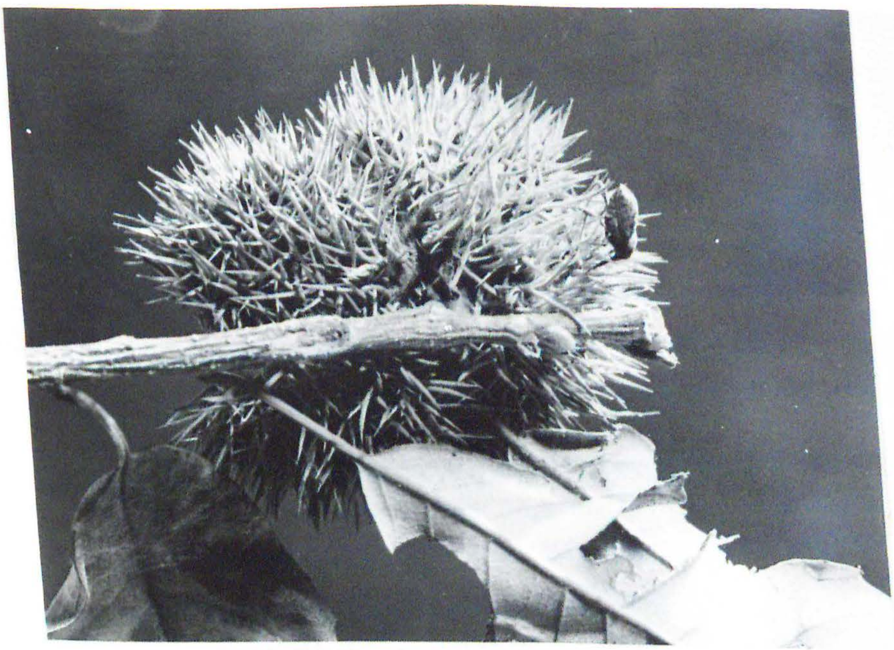


Figure II. A female Curculio auriger drilling a hole in a chestnut.

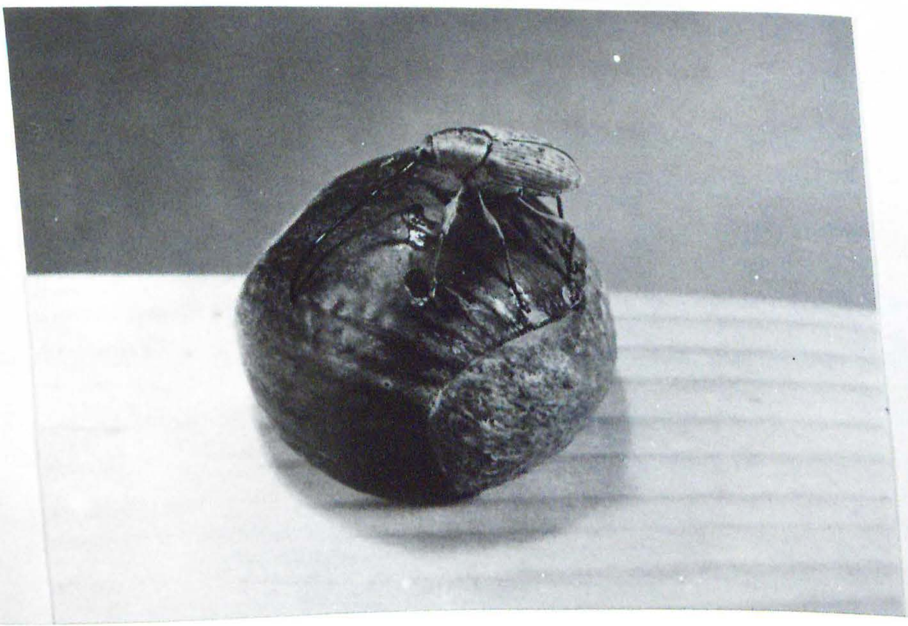


Figure III. A female Curculio proboscideus mounted on a chestnut.

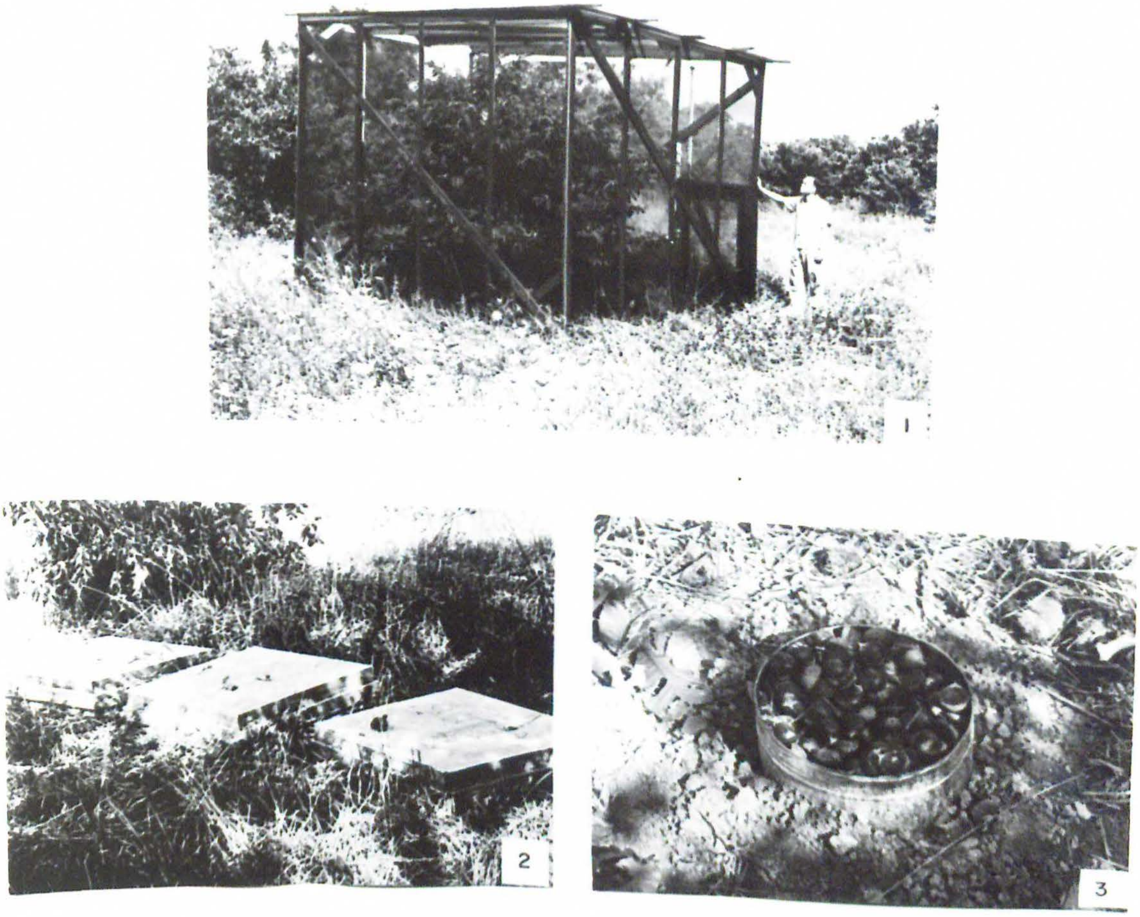


Figure IV. Cages used for rearing and behavior studies.
(1) Tree cage used primarily for behavior studies.
(2,3) Cages for rearing chestnut weevil larvae.

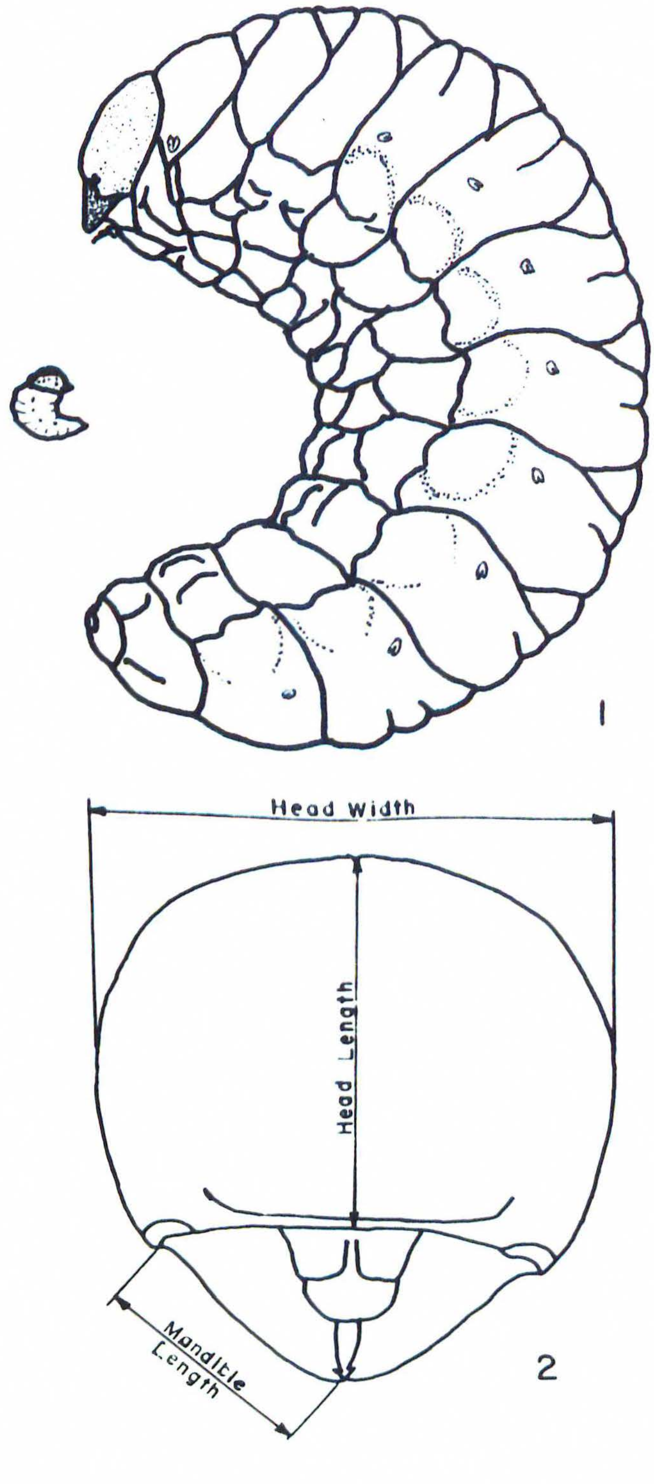


Figure V.

(1) The comparative sizes of first and fourth instar Curculio proboscideus. (x 10).

(2) The location where head measurements were made.

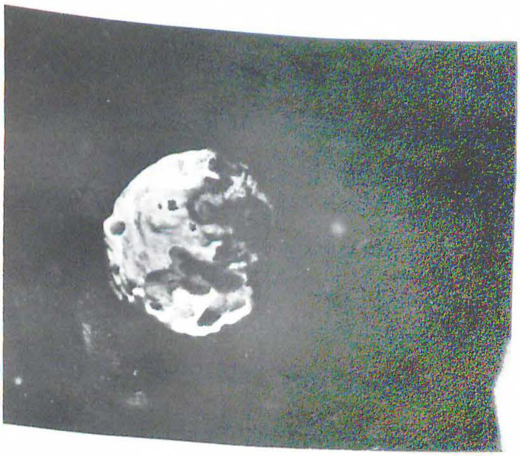


Figure VI. Damage to the kernel caused by chestnut weevil larvae.

Figure VII. Exit holes made by chestnut weevil larvae.

Figure VIII. Earthen cell made by the larva. (x 2).

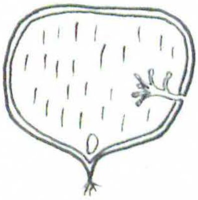


Figure IX. A diagram of the egg galleries of <u>Curculio</u> <u>auriger</u>.

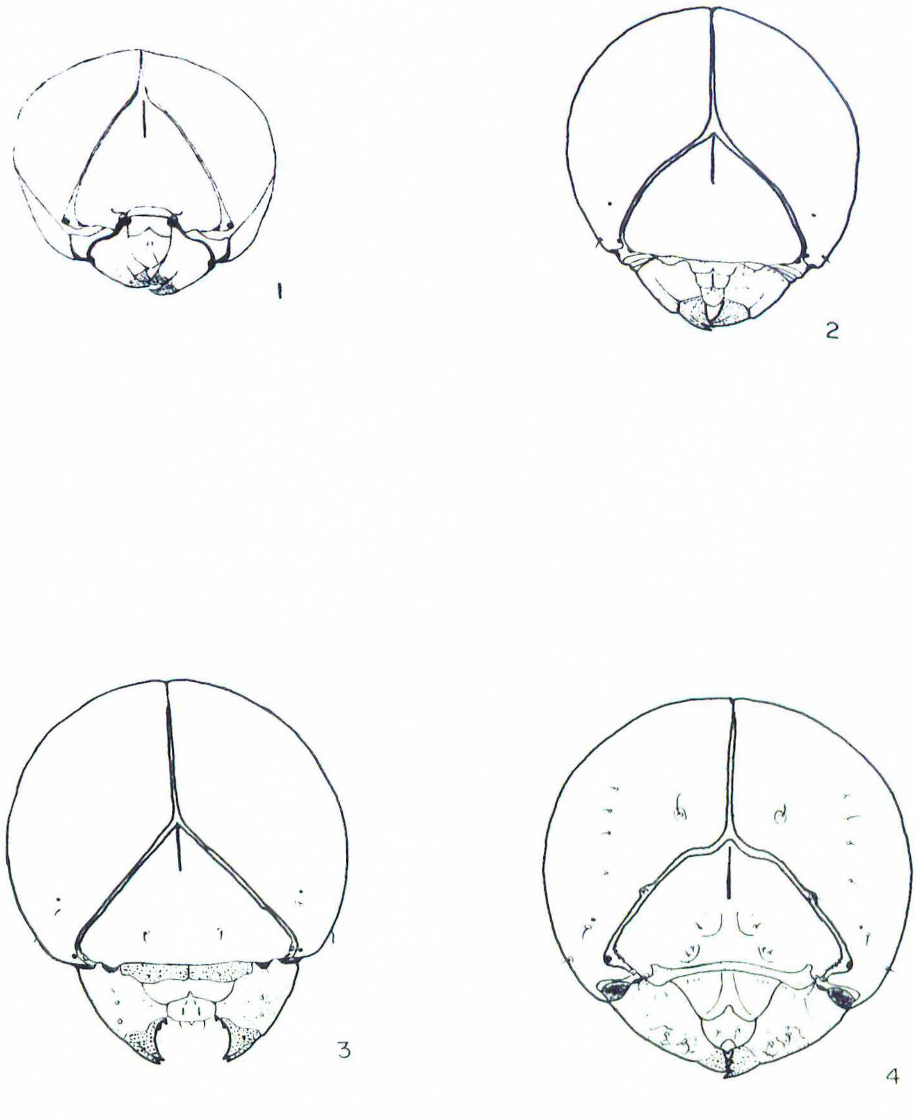
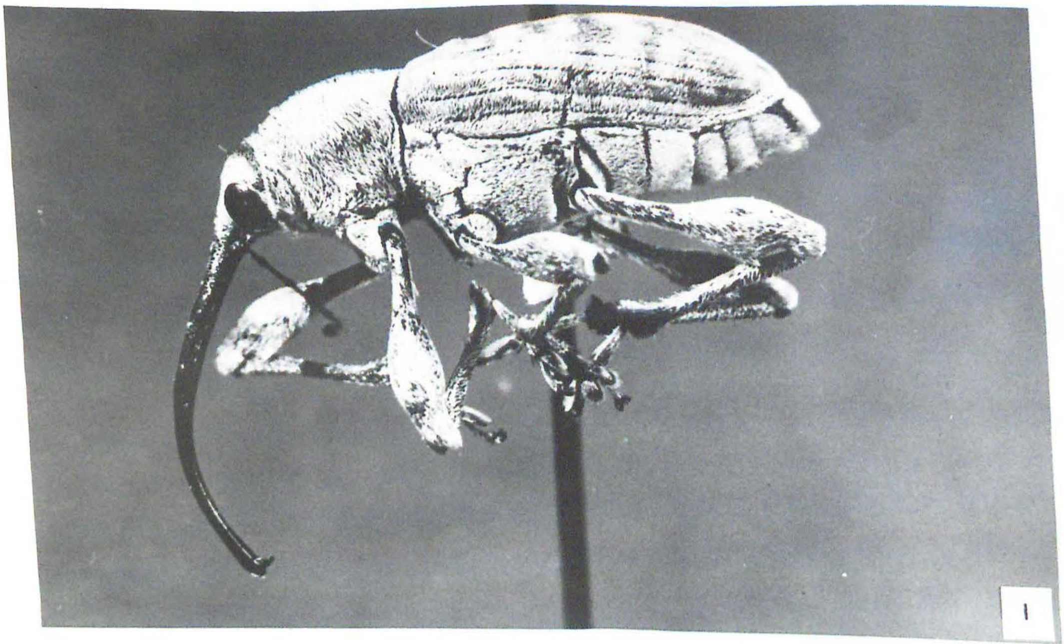


Figure X. Larva head capsules of the four instar stages of *Curculio proboscideus*.



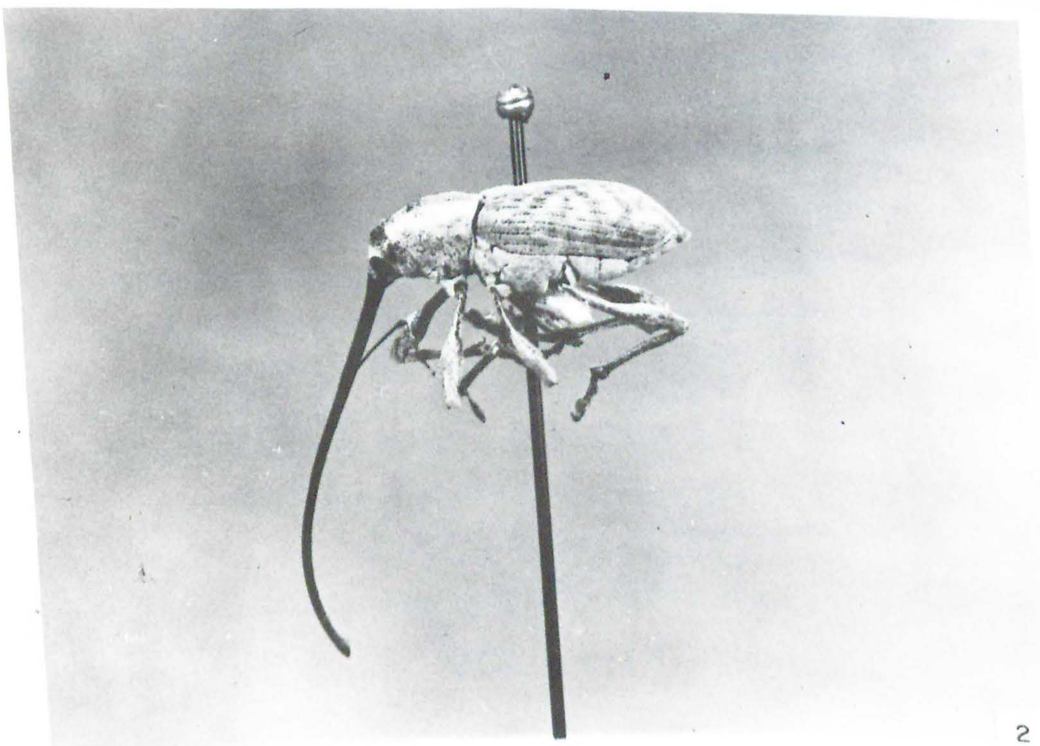


Figure XI. Curculio proboscideus.

(1) Male. (x 9) (2) Female. (x 5)

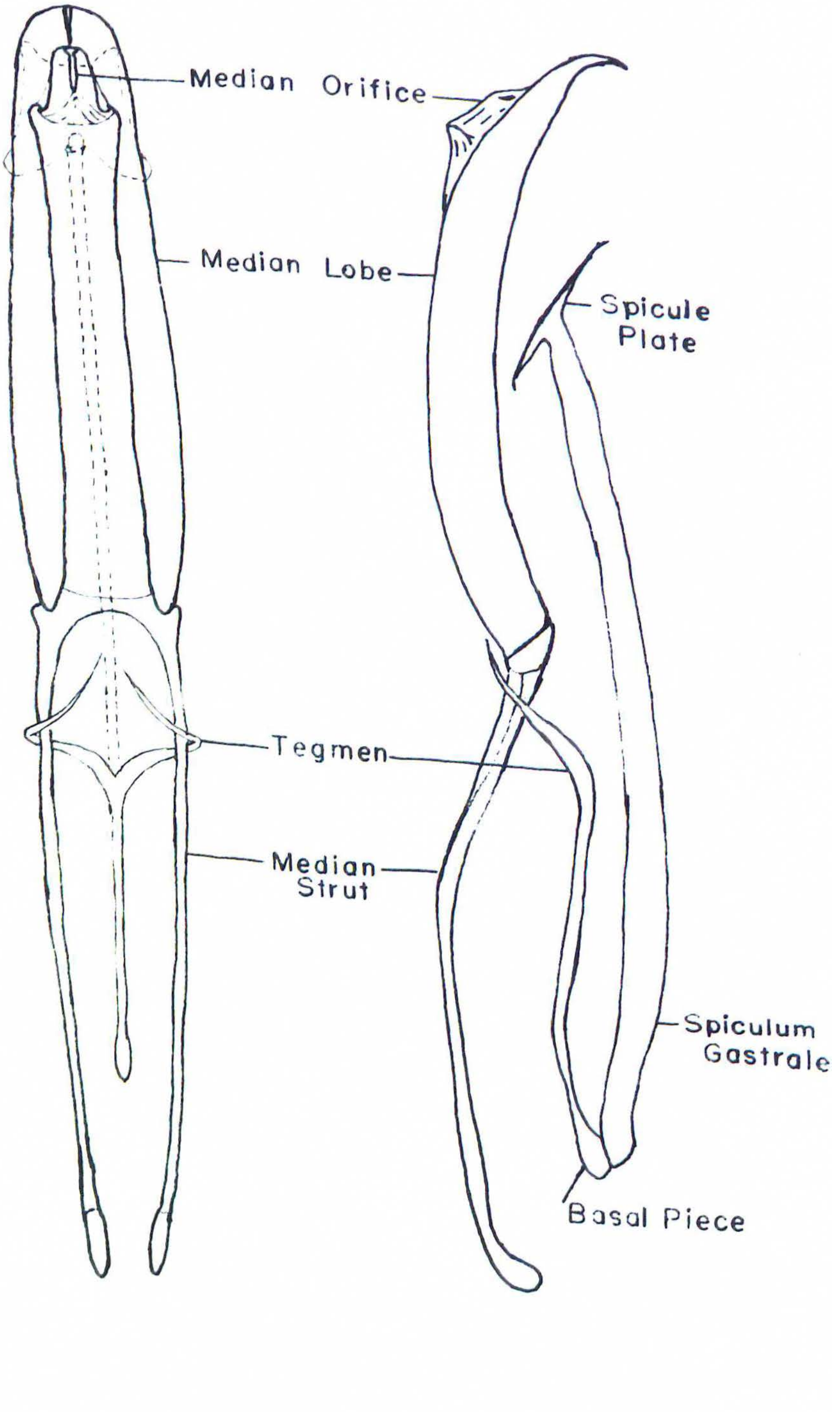


Figure XII. Copulatory apparatus of the male Curculio proboscideus (Left) Dorsal aspect. (Right) Lateral aspect. (x 37).

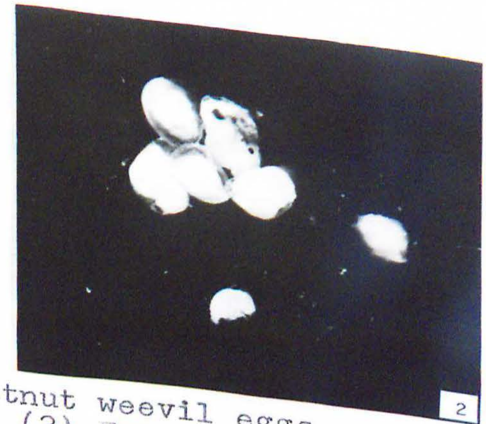


Figure XIII. Chestnut weevil eggs.
(1) Eggs of C. auriger (x 13).
(2) Eggs of C. proboscideus (x 10).

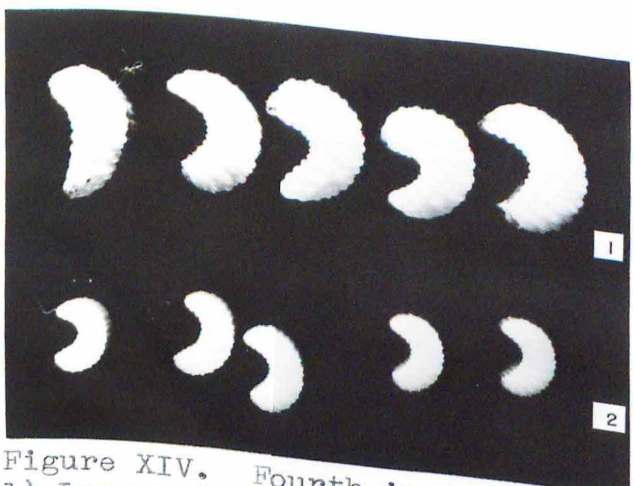


Figure XIV. Fourth instar larvae.
(1) Larvae of C. auriger (x 1.6)
(2) Larvae of C. proboscideus (x 1.5)

Figure XV. Pupae.
(1) C. auriger (x 3.8).
(2) C. proboscideus (x 2)

(Taken from Brooks and Cotton.)

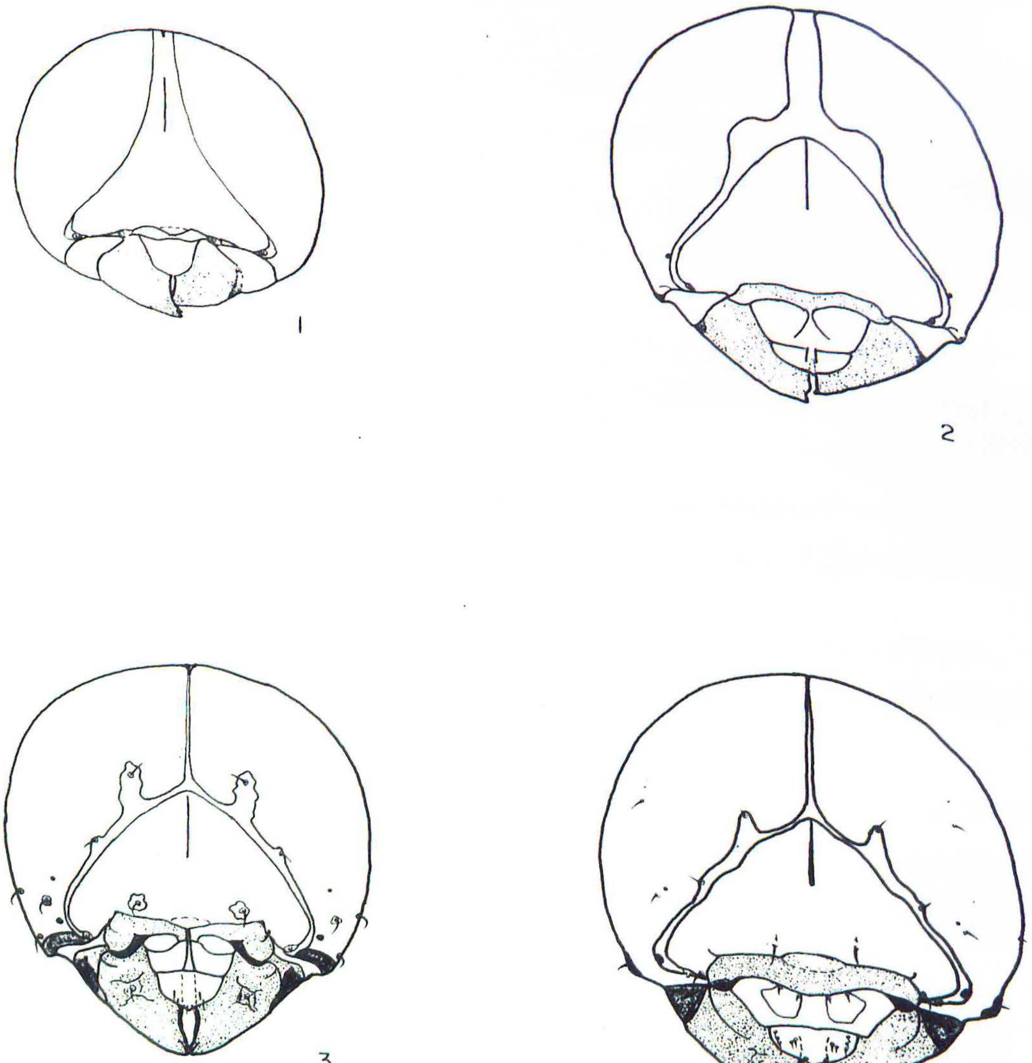


Figure XVI. Larva head capsules of the four instar stages of *Curculio auriger*.

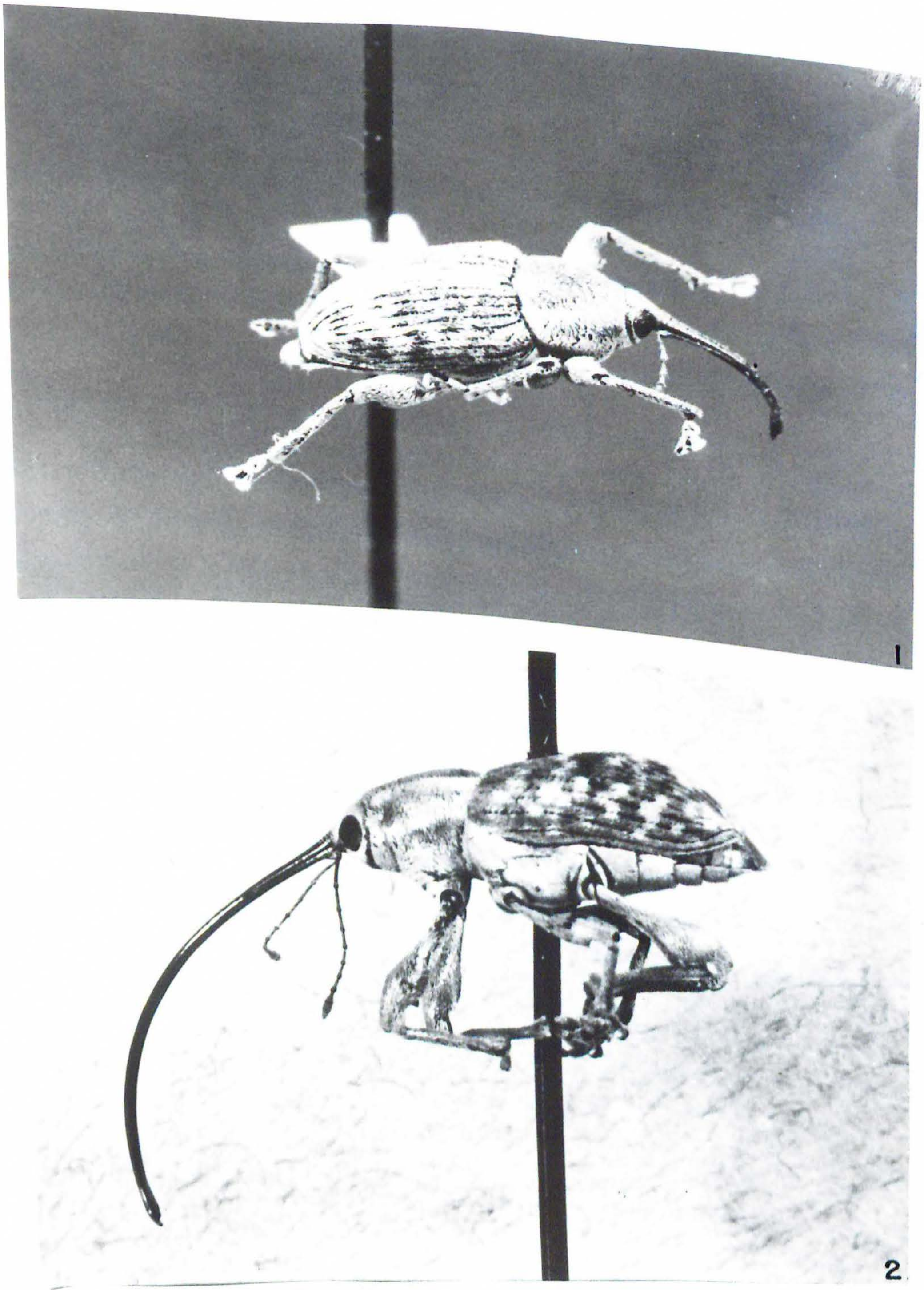


Figure XVII. Curculio auriger.

(1) Male. (x 9). (2) Female. (x 7.5).

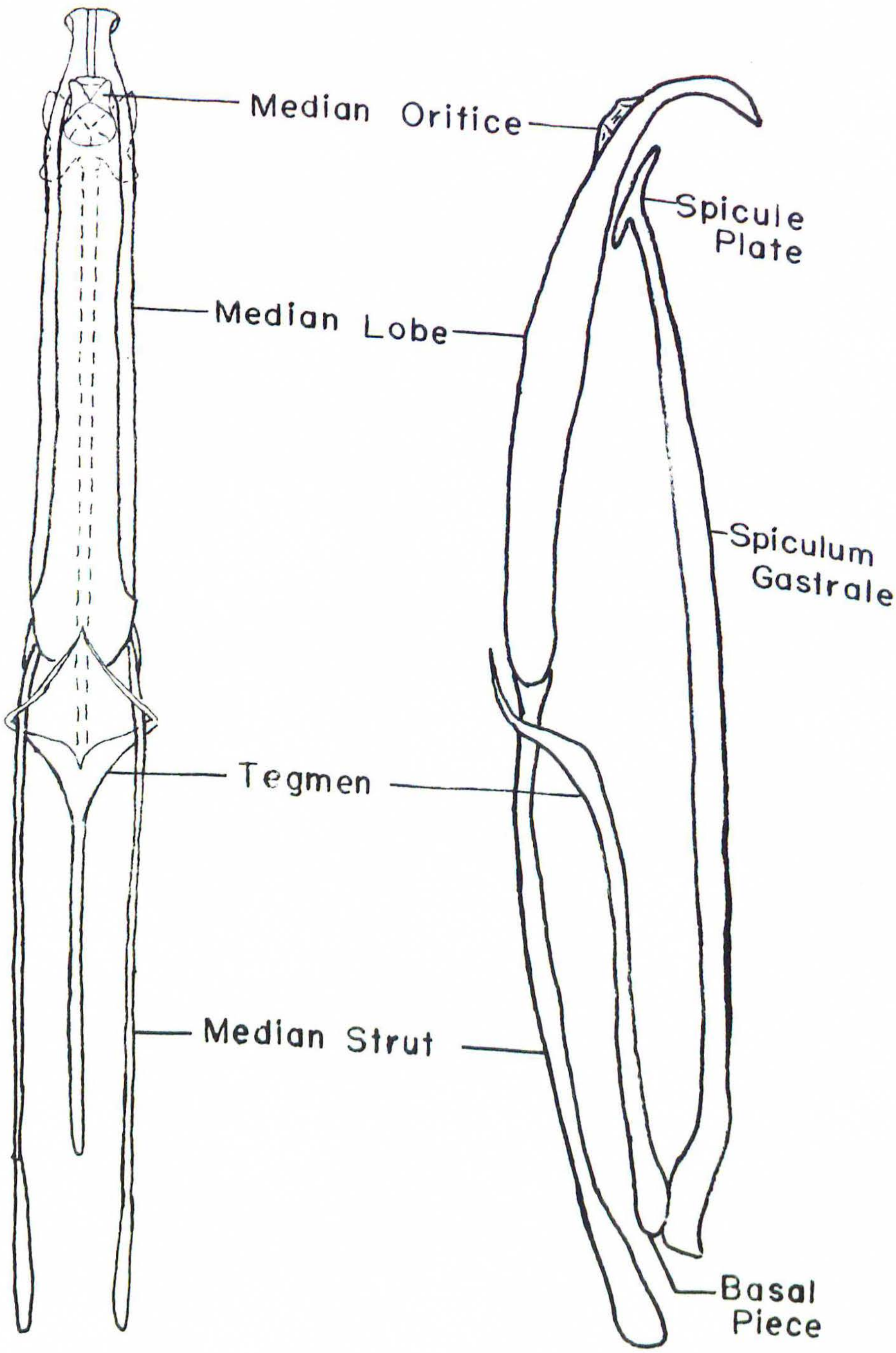
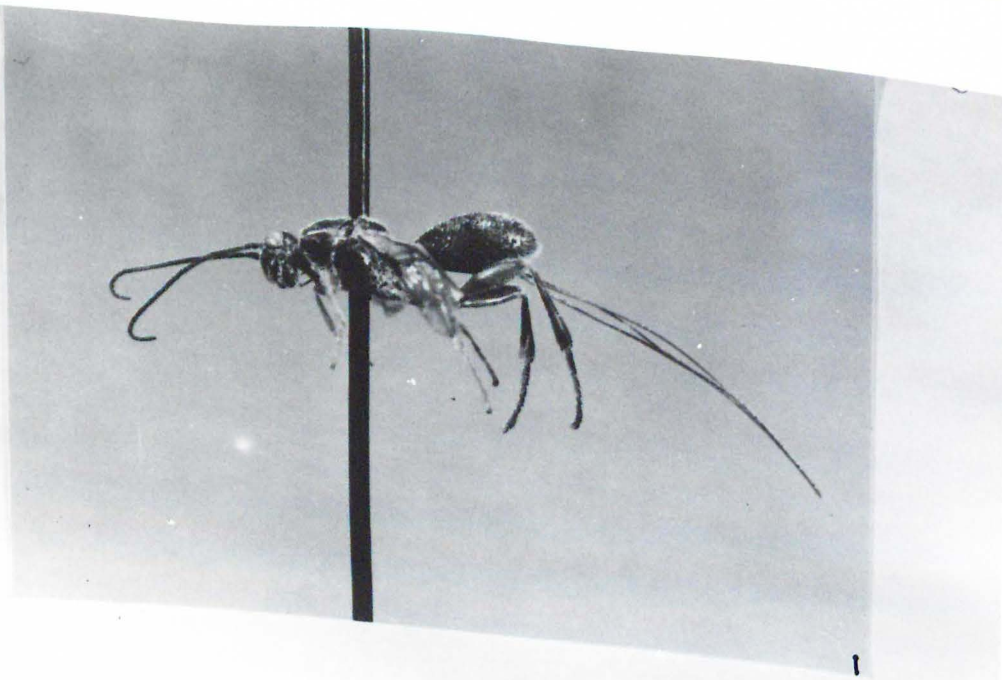


Figure XVIII. Copulatory apparatus of the male Curculio auriger. (Left) Dorsal aspect. (Right) Lateral aspect. (x 49).



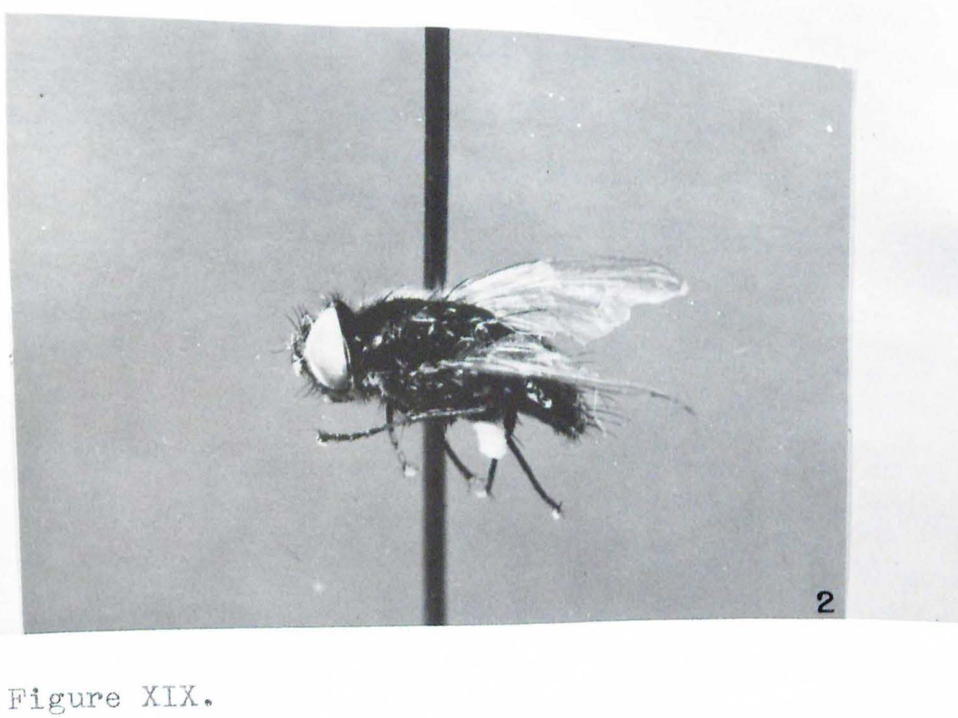


Figure XIX.

(1) The adult braconid parasite <u>Urosigalphus armatus</u> (x 5).

(2) The adult tachinid parasite <u>Myiophasia nigrifrons</u> (x 5).

Figure XX. The Chinese chestnut *Castanea mollissima*.

Figure XXI. Foliage damage caused by *Cyrtepistomus castaneus*.

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