A MORPHOLOGICAL STUDY OF THE PROBOSCES AND OBSERVATIONS ON THE FEEDING HABITS OF FRUIT-PIERCING MOTHS

by

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Moths that feed on fruit in orchards and gardens in and around Pretoria. The moths to the left of the dividing line are able to pierce intact fruit while those to the right are unable to do so.

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I. INTRODUCTION

Certain noctuid moths are known as fruit piercers, mainly in the tropical and subtropical regions of the world. These so-called "fruit-piercing moths" or "fruit-sucking moths" pierce fruit with their proboscis and suck the juice, causing damages of considerable economic importance. Differences of opinion exist as to whether certain species are capable of penetrating the intact skin or flesh of fruit. From a survey of the literature it appears that in the past control measures may also have been directed against species of uncertain status, that is, species with "unmodified" proboscis, being unable to pierce sound fruit. Little study has been done on the morphology of the proboscis of different fruit-piercing moths and experimental work on caged moths with fruit is scant.

In the present study the behaviour of the moths in the orchard and their choice of damaged or intact fruit was recorded. Caged moths were given fruit of varying hardness to test their ability to penetrate either skin or flesh of the fruit. A morphological study of the proboscis provided a means of correlating its structure with the ability of a moth to pierce fruit.

Additionally, information was gathered on the preference of moths for different kinds of fruit, the presence of different species of moths on fruit throughout the night and the return of moths to the same source of food on subsequent nights.

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II. LITERATURE REVIEW

A. Fruit-piercing moths

From a study of the literature on fruit-piercing moths as given under X. REFERENCES, the following genera of noctuid moths are regarded as injurious to fruit to a greater or lesser extent: Achaea, Adris, Anomis, Anua, Audea, Calpe, Cocytodes, Cyligramma, Dermaleipa, Egybolis, Ercheia, Gonodonta, Heliophisma, Hypocala, Lacera, Lagoptera, Miniodes, Mocis, Oraesia, Othreis, Parallelia, Pericyma, Plusiodonta, Polydesma, Pseudotolna, Scolyopteryx, Serrodes, Sphingomorpha, Tiracola and Tolna.

These moths are strong flyers and may cover long distances from their breeding grounds to fruit orchards (Tryon, 1924; Hargreaves, 1936; Weddel, 1944; Kriegler, 1962; Myburgh, 1963; Bosch, 1970), where they attack the fruit at night and hide in nearby vegetation during the day. A large variety of tropical, subtropical and temperate fruits are attacked (Jack, 1922; Rakshpal, 1945; Hargreaves, 1936; Weddel, 1944; Comstock, 1963; Bänziger, 1969).

Damage to fruit is seen externally as pin-prick holes where the proboscis penetrated the skin of the fruit. Under the skin the cells of the flesh are lacerated and the juice sucked out, leaving a spongy dry area. Secondary rotting organisms, small beetles and drosophilid flies gain entrance through the feeding holes and the fruit decays and drops (Hargreaves, 1936; Rakshpal, 1945; Todd, 1959; Neubecker, 1966; Swart, 1969).

Fruit-piercing moths are reported as pests mostly from the tropical and subtropical regions of the world: Africa,

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Madagascar, Ceylon, India, Japan, China, Phillippines, Indo-China, Malaysia, New Guinea, Australia, Pacific Islands, South and Central America and the southern parts of North America (Hargreaves, 1936; Viette, 1948; Ebeling, 1959; Todd, 1959; Comstock, 1963). More recently Bänziger (1969) also recorded the occurrence of fruit-piercing moths in Europe.

Losses to fruit crops may be considerable. In South Africa fruit-piercing moths cause losses of more than R250 000 in the canning peach industry in epidemic seasons (Swart, 1969). In outbreak years 50% or more of the canning peaches in the Little Karoo are damaged by fruit-piercing moths (Whitehead & Rust, 1972). In the Eastern Cape in 1925, Gunn (1929) reported losses of between 15% and 70% in citrus orchards. Up to 90% damage to grapefruit crops, caused by Othreis spp., was reported from the Gold Coast (Cotterell, 1940). Clausen (1933) mentions instances where 20% to 40% of pummelo crops were lost due to attacks from Othreis fullonica (L.), while Todd (1959) also records 10% to 100% losses of orange crops in Mexico due to Gonodonta spp.

Larvae of most of the species are polyphagous (Neubecker, 1962; Forsyth, 1966), feeding on indigenous wild plants. They may, however, cause considerable damage to cultivated plants, as for example Achaea lienardi Boisd. defoliating black wattle, castor oil, eucalypts and citrus in South Africa (Webb, 1953).

Few cases are on record of experimental proof of the ability of different moth species to pierce and penetrate sound fruit with their proboscis. Jack (1916) states that the ability to pierce citrus fruit had been "definitely proved" for Othreis spp. and a Calpe sp. (species undetermined). Using caged moths, Neubecker (1962, 1966) proved

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that Sphingomorpha chlorea Cram. was unable to pierce sound grapes, whereas Othreis materna L. and Serrodes partita Fabr. with their piercing proboscis, riddled them with holes.

Srivastava & Bogawat (1969) describe the feeding process in relation to the cephalic muscles in O. materna. Swart (1969) described the manner in which S. partita pierces sound fruit. Bänziger (1970) gives a detailed account of the piercing mechanism of the fruit-piercing Calpe thalictri Bkh. and also recounts his interesting discovery of the skin-piercing blood-sucking Calpe eustrigata Hmps (Bânziger 1968, 1972).

Many methods to control the moths have been devised and applied with varying degrees of success. These include baiting with so-called Gunn traps (Gunn, 1925; Cotterell, 1940; Golding, 1945; Kriegler, 1957), the practice of trap trees (Nel & Hattingh, 1944; Kriegler, 1957; Smit, 1964), coverings for trees or fruit (Jack, 1916; Susainathan, 1923; van der Merwe, 1926; Clausen, 1933), early picking of fruit (Cotterell, 1940), controlled fruiting in citrus (Cotterell, 1940; Rakshpal, 1945), hand-picking the moths at night (Smit, 1964; Bosch, 1971a), removing the larval host plant (Susainathan, 1924; King & Thompson, 1958), sex attraction (Neubecker, 1966), introduction of egg parasites (Rao, 1969), employing cover sprays of repellents or insecticides on fruit (Susainathan, 1923; Kriegler, 1957, 1962; Bosch, 1971b) and repelling moths at night with light of different sources (Nomura et al, 1965; Whitehead & Rust, 1967, 1972; Bosch, 1971a,c; Myburgh & Whitehead, 1971).

Bats are considered by Hargreaves (1936) to be the main predators of Othreis spp., while Kriegler (1957) maintains that they decidedly play a part in decreasing the moth populations of Serrodes partita. Bosch (1969) mentioned the

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possibility of using ultra-sonic sound to repel moths, while she also suggested ways (1971a) in which baiting could be improved.

B. Lepidoptera mouthparts

The first study of the proboscis of Lepidoptera was undertaken by Reamur in 1734 (according to Breitenbach, 1882 and Kirbach, 1884). He observed that a proboscis splits into two equal halves, that tooth-like structures and threads accomplish the linkage and that three canals are seen in cross section. However, he regarded the proboscis as a structure on its own, unrelated to the mouthparts in other insects. Early researchers on Lepidoptera mouthparts were indebted to Savigny's discovery in 1816 (according to Breitenbach, 1882 and Kirbach, 1884) of the homologies of mouthparts in different insect orders and that the sucking tube in Lepidoptera was formed by the modified maxilla.

Kirby & Spence in 1823 (according to Breitenbach, 1882) noted the large number of rings and that each ring is moved by its own muscle. (These are the "exocuticular ribs" and "oblique galeal muscles" of Swart, 1969). They wrongly interpreted the two side canals of the proboscis as tracheae. Gerstfeldt in 1853 (according to Breitenbach, 1882) was the first to draw attention to the structure of the inner wall of a maxilla. He described it as a striated membrane (the "exocuticular bars" of Swart, 1969), reaching from one longitudinal bar to the other (the "dorsal bar" and "tooth and hook" of Swart, 1969) and independent of the outer chitinous bands ("exocuticular ribs"), the latter which may fork or coalesce.

McIntyre (1874) drew attention to the differences between the general structure of the haustella of Lepidoptera

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and that of an unidentified moth which had a modified haustellum tip. He wrongly assumed that the imbibed fluids pass into the food canal via apertures or papillous appendages on the proboscis tip. Burgess (1880) gives a short description of the galeae and their musculature and of the pumping organ of Danais archippus (Fabr.).

A concise summary of the works of earlier authors is given by Breitenbach (1882). He further elaborated on the structure of the chitinous bands ("exocuticular ribs"), the linkage mechanism and on the variations found in the structure of the proboscis tip. Kirbach (1884) made an extensive study of the sucking pump, its musculature and functioning and on the anatomy of the proboscis. He extended the earlier studies on the linkage mechanism and on the function of the sense organs on the proboscis tip.

In a comparative study of the mouthparts of Trichoptera, Micropterygidae and higher Lepidoptera, Kellogg (1895) established that the maxilla consists of the cardo, galea, stipes and sometimes the lacinia. Tillyard (1923) confirmed, through a study of the mouthparts of various genera of Micropterygidae, that the lepidopterous proboscis is formed by the elongated galeae. Snodgrass (1928, 1931) gave an account of the evolution of the insect head, including the mouthparts. Kristensen (1968) discussed briefly the morphological and functional evolution of the mouthparts of adult Lepidoptera as seen in the Eriocraniidae, a family representing a transition between the Micropterygidae and higher Lepidoptera.

The maxillae of all the different groups of Lepidoptera are described and figured by Philpott (1927), with emphasis on the maxillary palpi, but details of the galeae are not given. Snodgrass (1935) gives a general account of the

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morphology of the head and its appendages in Lepidoptera. Schmitt (1938) studied and compared the feeding mechanism as well as the coiling and the extension of the proboscis in various families of Lepidoptera. The latter aspect was further studied by Pradhan & Aren (1941), who also described the mouthparts of adult Scirpophaga nivella (Fabr.).

Charlanes & Gaumont (1960) discuss the ventral and dorsal linkage mechanism of the galeae of some lepidopterons. Srivastava & Yadava (1969) described the morphology of the head and mouthparts of the pyraustid Leucinodes, showing inter alia that the proboscis of this moth has no exocuticular ribs and that a lacinia is distinguishable.

The comprehensive study by Eastham & Eassa (1955) on the anatomy, morphology and functioning of the mouthparts of Pieris brassical L., surpasses the works of earlier authors. The different opinions held on the mechanism of extension and coiling of the proboscis of Lepidoptera, starting in 1734 with Reamur, are reviewed. Later Swart (1969) also discussed in some detail the coiling and extension mechanism in Serrodes partita. After a series of experiments with moths belonging to different families, however, Bänziger (1971) refuted the existing theories on coiling and extension of the proboscis.

A brief description of the morphology of the sucking-pump of Papilio demoleus L. is given by Srivastava (1956). He later extended this study to the skeleto-muscular mechanism of the same butterfly (Srivastava, 1957). A similar study was also published in the same year by Vaseduva (1957). Eassa (1963a,b) investigated the metamorphosis of the cranium of P. brassicae and briefly discussed the appendages of the head of the adult lepidopteron.

The work of Swart (1969) comprises an exhaustive study

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of the anatomical and morphological structure of the cranium, the cranial appendages and the sucking pump of the fruit-piercing moth Serrodes partita. Srivastava & Bogawat (1969), Swart (1969) and Bänziger (1970) all describe the way in which the proboscis of Othreis, Serrodes and Calpe respectively pierce fruit, as well as the functions of various structures on the proboscis tip during piercing and subsequent feeding, but their interpretations differ.

The specialised proboscis tip of Othreis fullonica, which had become known as a destructive pest of oranges in Australia, was illustrated and described by Künckel (1875), Darwin (1876) and Read (1879).

All early authors had noticed the different sense organs found on the proboscis, usually at the tip. Reamur in 1734 (according to Breitenbach, 1882 and Kirbach, 1884) was the first to notice membraneous platelets, of which he erroneously thought that they supported the weak proboscis tips. Müller in 1877 (according to Breitenbach, 1882) described the simple organ of taste or touch as a circular plate with a papilla in the centre. These organs could develop greatly.

Various types of modified sensilla, termed "sap borers", were described and illustrated by Breitenbach (1882). These are all derived from the simple hair type sense organ and he considered them to have a tactile function only. Breitenbach regarded Egybolis vaillantina Stoll., Othreis spp. and an Achaea sp. as moths capable of boring into fruit.

Kirbach (1884) described the sensilla in the food channel as "channel pegs", also with a tactile function and derived from the simple hair type sensillum. Similar trichoid sensilla were observed by Eastham & Eassa (1955) and

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by Swart (1969), the latter author who believes that they may serve as chemoreceptors. Kirbach (1884) considered the "sap borers" primarily as tactile sense organs, with a secondary mechanical function if they were armoured. He presumed that the saliva, forced outwards through the food channel by the salivary pump, served to dissolve solids or to dilute sticky fluids imbibed as food.

The sense organs on the proboscis tip of Diana vanillae L. are regarded by Marcus (1949) as sensilla basiconica with a "hygrometric" function. Frings & Frings (1956) regard the same type of sensory organ in various other Lepidoptera spp. as contact chemoreceptors. Kernbach (1958) suspects the sensory hairs on sphingid probosces to act as olfactory sense organs.

In the Noctuinae alone Taylor (1957) found great variations in the development of the proboscis: from soft ribbon-like types to the fruit-piercing forms, the latter which possess stout teeth and strong pointed tips. Jack (1922), Todd (1959), Büttiker (1962), Neubecker (1966), Swart (1969), Srivastava & Bogawat (1969) and Bänziger (1970) all comment on the modified and strengthened proboscis tip in fruit-piercing moths.

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III. MATERIAL AND TECHNIQUE

A. Orchard Studies

Fruit-piercing moths were studied at night with the aid of a head lamp in orchards. For closer observation of the movements of the proboscis during piercing and sucking, a 10× magnifying glass was used. When moths were busy feeding, they only flew away when a branch on which they were sitting, was suddenly moved or when the observer breathed while observing them from close by.

All observations were made at irregular times in peach orchards at the Roodeplaat Horticultural Research Institute, north-east of Pretoria, and at the Horticultural Section of the University Experimental Farm, Pretoria during the summers of 1965-1966, 1968-1969 and 1970-1971.

The following method was employed to survey the different moth species at night: the names of the moths and numbers seen, were written down while going around a particular tree. This took from 3 to 15 minutes, depending on the number of fruit and the number of moths. Care was taken to disturb neither the moths in the tree. nor those feeding on the fruit lying on the ground. Although this method necessitates a proper knowledge of the morphological characteristics and habits of the moths for correct identification, it is preferable to the one where moths are caught and counted later. With the latter method some moths get away, others cannot be reached whilst still others are disturbed by moving the branches. Sight records eliminate the personal factor of catching rarer moths first when common ones are present in great numbers. The distribution of moths in a tree is also determined by the distribution of fruit in the tree and the number of fruit on the ground. With sight records the latter

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two factors mentioned do not influence the counts that are made.

During the moth surveys described above, records were also kept of whether individual moths were feeding on intact or damaged fruit.

B. Caged Moths

Moths were caught alive on fruit with a glass beaker, diameter 4 to 5 cm, and a piece of carton, 10×10 cm (Fig. 13). They were then transferred to 45×45×50 cm cages, made of wire gauze and wood. Pared and unpared fruit of varying hardness were put in the cages for the moths to feed on. The fruit was pared by cutting a slice of 3 to 5 mm maximum thickness from the surface of the fruit.

The hardness of the fruit was tested as soon as possible after moths had penetrated the intact fruit or the exposed fruit flesh with their proboscis. The method adopted to test the hardness is that suggested for peaches by Haller (1941) with a USDA fruit pressure tester. The fruit is held in one hand and the cylindrical plunger of the tester pointed squarely against the surface. The plunger is pressed into the fruit until it penetrates to a mark on its side. The pressure is then released and the reading is indicated by a slide on a scale.

The tester used in the experiments with caged moths was calibrated from 3 to 30 pounds (1,4 to 13,6 kg). This is the pressure required to force the cylindrical plunger, which is 8 mm in diameter and has a blunt halfround tip, into the fruit flesh to a depth marked on the plunger.

The greater part of the surface of the fruit used in the

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experiments with caged moths was covered with a layer of paraffin wax in order to restrict the area exposed to the moths and thus to simplify the detection of punctures and also to restrict piercing to the cheeks of the fruit (Fig. 15). Peaches left from 8 to 14 hours in a 1% Methylene Blue solution in water showed up the punctures and damage to the fruit flesh.

C. Morphological Studies

In the morphological studies the heads of moths were cleared in a 10% NaOH solution for 36 hours, transferred to distilled water for 6 hours and then stained.

Both fresh material and material that had been fixed and preserved in Bouin's fluid for variable lengths of time was used initially. Very poor staining was obtained when the normal staining procedures (see below) were followed. Very often there was no staining despite repetitions with other specimens and newly prepared stains. Specimens that had been kept in Bouin's fluid, however, always stained better and this fixative was thus used in subsequent staining procedures.

The stains used were Basic Fuchsin, Mallory's triple stain (Pantin, 1962) and Hamm's modified Azan stain (Hamm, 1966). The latter method gave the best results. For an examination with the compound microscope, a proboscis was removed from the head, a single galea placed on a glass microscope slide and the galea covered temporarily with a cover glass after a drop of water or 90% ethyl alcohol had been added.

The galeae were not mounted permanently because they had to be moved or turned around occasionally in order to observe and count the structures on all sides. Since the stains used

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in the staining methods quoted are washed with distilled water or ethyl alcohol, these two fluids were used in the temporary mounts. It was noticed, however, that the colours started fading after 6 to 12 hours. In most probosces only the proximal and distal regions stained well.

When staining was done with the 1% Basic Fuchsin solution in water, the specimens were not transferred to Bouin's, but were kept in distilled water for 15 minutes and then stained for 15 minutes. Basic Fuchsin stains cuticle red: the exocuticle of the ribs, barbs, blades and sclerotized tip stained darker than the endocuticle between the ribs and also the exposed areas without ribs on the distal part of the galeae of some species. The hairs and the structures constituting the dorsal linkage very often showed no staining and remained clear.

The preliminary mordant in Mallory's triple stain made no difference to the subsequent staining. The heads were kept in the Acid Fuchsin for 1-2 minutes, compared to 15 seconds suggested by Pantin (1962), otherwise staining was insufficient. The endocuticle between the ribs stained blue. The bars of the food channel stained blue-green, the dorsal bar purple and the remaining exocuticular structures pale orange.

The modified Azan stain used by Hamm (1966) differentiated the endocuticular and exocuticular structures of the proboscis very well. The endocuticle was stained light blue, the exocuticular bars of the food channel blue-green and the dorsal bar dark red to purple. The dorsal and ventral linkage structures stained from orange through light red to a light purple. Other exocuticular structures stained orange to red. In the staining procedure the 50% acetic acid was omitted and the specimens kept in the Azocarmine solution for 30 minutes (which is longer than the prescribed 15 minutes)

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and in the counter stain for 5 minutes (15 minutes prescribed).

The proboscis of Achaea sordida Guen., Calpe provocans Wlk. and Othreis materna L. were stained in Mallory's or Hamm's stain as described and then used for microtomy. The specimens were kept in absolute ethyl alcohol for 2 hours, in xylene for 1 hour and in melted paraffin wax for 12 hours. Transverse sections with a thickness of 10,0 microns and 7,0 microns were cut and the sections heated on microscope slides to a temperature where the wax just started to melt. These sections were used to make a generalized drawing of a transverse section through the apical region of the proboscis of fruit-piercing moths (Fig. 3).

Drawings of the lateral view of the distal region of the galeae were made with the aid of a squared eyepiece of a stereoscopic microscope and with graph paper. In the drawings only the exocuticle of the galeae tip is stippled to show the extent of sclerotization. The heavily sclerotized ridges in Othreis and the areas around the barbs in other genera are shown in black.

Unless specifically mentioned, the terminology used by Swart (1969) is adopted for the description of the proboscis and associated structures.

D. Marking Moths

In order to establish whether moths return to the same feeding place on subsequent nights, they were caught on fruit, anaesthetized with ethyl ether, marked and released the same night. More moths were marked, however, when caught individually and held in the hand without etherization. The dorsal hair covering on the thoraces of the moths was brushed off with a piece of foam plastic. Small coloured "Zellit"

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discs, used for individually marking queen honey bees, were pasted onto the exposed dorsal surfaces. These discs were obtained from Chr. Graze, 7057 Endersbach, West Germany.

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IV. ORCHARD STUDIES

A. Behaviour of Moths

When noctuid moths approach fruit, they fly from side to side and up and down if they are from 1 m to 5 m distance from the fruit. Thereafter the approach is more direct, with extended legs, antennae turned forward and the proboscis usually partly uncoiled.

After landing on the fruit the proboscis and the antennae are used to explore the fruit surface, but especially the proboscis of non-piercing moths locate the punctures of piercing moths on fruit that are otherwise undamaged. The antennae move up and down, touching the fruit surface alternatively. When a suitable feeding spot has been located and feeding has commenced, the antennae are usually turned back and kept next to the body.

Feeding may continue uninterruptedly for five to six hours on the same fruit, as observed with two Sphingomorpha chlorea Cram. A resting period of up to two hours may then occur with retracted proboscis, after which feeding is resumed. (This data was not collected for other species.) At intervals during feeding moths forcefully eject anal fluid while the abdomen is raised between the wings. Calpe triobliqua Saalm. may curve its abdomen upwards and forwards to discharge the fluid anteriorly over its head. In moths that have fed for several hours, the large amounts of excreted fluid is light in colour and almost clear and may be sucked up by other non-piercing moths.

When two moths happen to come too near each other while feeding, or when crowding occurs on fruit, the larger species shows an aggressive reaction: a quick sideways movement is

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made towards the approaching moth which is simultaneously "kicked" with the middle leg while the wings vibrate for one or two seconds. This behaviour was observed in Achaea finita Guen., Achaea sordida Wlk., Serrodes partita (Fabr.) and Sphingomorpha chlorea Cram. The following moths, recorded simultaneously on a single peach, serve to illustrate an extreme case of crowding:

4 Anomis spp., 2 Achaea catella Guen.,
5 A. finita, 5 A. sordida and 1 S. chlorea.

After feeding moths may display two cleaning reactions. In the first the proboscis is coiled and uncoiled several times away from the head and labial palpi (Fig. 1b,c). During this movement saliva is secreted from the apex of the proboscis and sucked up again. This is done to free the proboscis of sticky juices. In the second cleaning process the proboscis is coiled and uncoiled between the labial palpi. Each palpus has a labial brush (Fig. 2 lab. br.) of short, stiff hairs on the median side of the first segment. The brushes serve to remove larger particles of vegetable matter adhering to the proboscis.

Moths in orchards with ripe fruit did not restrict their feeding to the fruit alone. During warm, dry weather non-piercing moths were seen to suck the dew on the grass. Extra-floral nectaries on the petioles of plum leaves were visited and a sticky, slightly sweet exudation of quick grass (Cynodon dactylon Pers.) was imbibed. The sap from the injured trunk of a plum tree was also sucked up.

During April 1970 on the University Experimental Farm, a time when there was no fruit in the orchard, noctuid moths were observed to suck nectar at night from sunflowers (Helianthus annuus L.) planted next to the orchard. The moths included Achaea sordida, A. finita, Helicoverpa

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(= Heliothis) armigera (Hübn.) and different Agrotinae.

A flowering White Box (Eucalyptus albens Miq.) also attracted large numbers of different noctuid moths, including Achaea spp., at night during March 1970 near the orchard on the University Experimental Farm. Webb (1953) mentioned the possibility of Achaea catella moths feeding on the nectar of eucalypt flowers for their energy requirements during migration.

Pollen grains were noticed on the proboscis or in the food channels of the proboscis of Cyligramma latona Cram., Achaea finita and A. sordida. One Achaea catella had an Asclepias pollinium tightly around the distal part of its proboscis.

During feeding and during resting, moths did not react to strong torch light. Apart from feeding and the cleaning of proboscis and antennae, no other activities were ever observed in orchards. Agrotis and Euxoa spp. were seen copulating between 00h00 and 04h00 near the fruit on which they had previously fed. At dawn all moths left the orchard to hide in dense vegetation. Many remained in the orchard if weeds were present.

B. Process of piercing and sucking

Moths that are not capable of piercing intact fruit explore the fruit surface with the distal third or quarter of the proboscis, which is held against and moved across the fruit. These "twitching movements" (Swart, 1969) can also be described as a "palpation" (Bänziger, 1970) of the fruit surface by the proboscis tip. Lateral movement of the proboscis, which according to Eastham & Eassa (1955) and Swart (1969) is restricted due to the closely packed laminae constituting the

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exocuticular bars of the food channel, is greatest in the tip which is quickly moved from one side to the other (Fig. 1d).

When a puncture is found, the proboscis is inserted and feeding commences. The head is slowly moved up and down with each probe, but a simultaneous quick continuous oscillating movement of the head (indicated by arrows in Fig. 1f,k) accompanies the probing. Neubecker (1966), Bänziger (1968, 1970) and Swart (1969) are the only authors who noticed this oscillation movement of the head, but only Bänziger explained the reason for it.

Careful observation of feeding moths with the aid of a magnifying glass and torch revealed that, simultaneously with the oscillating movement of the head, the two galeae slide to and fro alongside each other. This greatly increases the effectiveness of the various kinds of "sap borers" to pierce or rasp the cells of the flesh. This sliding of the galeae (the "anti-parallel movement" of Bänziger, 1970) also explains the relatively few and slow probing movements which, taken alone, would not liberate the same amount of fruit juice. In this study the discovery of the sliding of the galeae and its importance in the process of piercing, was made independently from that by Bänziger.

When Neubecker (1966) compared the feeding habits of Sphingomorpha chlorea and Serrodes partita, he mentioned the quick up and down probing of S. chlorea as an obvious difference. This species in actual fact shows only a very slight sliding movement of the galeae, the least of all the moths studied in this respect.

Moths displaying obvious oscillating movements of the head and simultaneous sliding of galeae are Achaea catella, A. finita, A. sordida, Anua dianaris Guen., A. tirhaca Cram.,

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Pericyma atrifusca Hmps., P. scandulata Feld. and Serrodes partita. The following moths show less oscillation of the head, coupled with only a slight sliding of the galeae: Agrotis sp., Anomis sabulifera Guen., Grammodes stolida Fabr., Parallelia Algira L., Sphingomorpha chlorea and Spodoptera spp. The opportunity to observe the sliding of the galeae in other species did not arise.

On 15.2.1971 a nymphalid butterfly Charaxes saturnus Butler was observed to feed on a damaged soft ripe peach in daytime in the orchard on the University Experimental Farm. It sucked up the peach juice while keeping the proboscis in a position as shown in Fig. 1a for S. chlorea, but it also executed some feeble probing movements during which no sliding of the galeae was noticed. Golding (1945) observed the satyrid butterfly Melanitis leda ismene Cram. piercing (sic) a grapefuit on a tree.

Moths that are capable of piercing intact fruit behave differently before feeding commences compared to those species that cannot pierce. Having settled on the fruit, the piercing moths press the tip of the proboscis against the skin of the fruit. Palpation of the fruit with the proboscis occurs less often than with the non-piercers. The proboscis may be kept straight down (Fig. 1j) or curved (Fig. 1g-i). It is then vibrated very quickly with a simultaneous oscillation of the head, although this oscillation is less obvious than during feeding after a hole has been pierced.

The rapidly vibrating proboscis appears like a spindle either along its entire length (Fig. 1f,k) or at the apex (Fig. 1g,h). During the oscillation the sharp galeae tips are alternatively forced into the skin at the same mark, while the spindle-like vibration has a slight boring action.

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Srivastava and Bogawat (1969) describe the way in which Othreis materna gains entrance into hard fruit with its proboscis. The fruit is "rubbed" with the distal part of the proboscis to cause a "slit like wound" into which the straightened proboscis is then inserted. None of the piercing moths in the present study were ever seen to execute this kind of piercing action.

Once the skin has been pierced, feeding commences as already described. The probing action may eventually be extended to all sides of the entrance hole. Feeding takes place with the visible part of the proboscis kept either straight or curved. Occasionally the whole proboscis is inserted into the fruit.

When moths feed on top of the fruit, probing and piercing is augmented by a movement in which the middle legs support the body which is lowered anteriorly and raised posteriorly. However, when moths hang upside down, the whole body but more so the anterior part, is slightly drawn towards the fruit.

During feeding the so-called "knee-bend" of the proboscis (Fig. 1d: k.b.) is usually noticeable. This is the region in which, according to Eastham & Eassa (1955) and Swart (1969), full extension of the proboscis is resisted due to the presence of a secondary group of oblique muscles. However, at times this region of bending is not recogniseable as in Fig. 1 i,j which shows two feeding postures of Pericyma scandulata.

In peaches the typical symptom of fruit-piercing moth damage is a dry spongy area (Fig. 16) up to 2 cm in diameter below the entrance hole. This area soon turns brown (Fig. 17), rots and peaches drop from the trees. Often drosophilid

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flies and occasionally also small beetles enter the hole made by the proboscis of the moths. The flies lay their eggs (Fig. 18) and the emerging larvae further hasten fruit decay.

Liquid squirted through the anus onto fruit or leaves is occasionally reliquified with saliva after it has dried and it is then imbibed. This behaviour is found among non-piercing moths and only once was it observed in Serrodes partita. In this case the posture of the proboscis (Fig. 1e) is in contrast with that of non-piercing moths where the distal third of the proboscis is held flat against the substrate, as in Fig. 1d. An almost similar posture of the proboscis in Sphingomorpha chlorea while reliquifying dried fruit juice was observed (Fig. 1a). It is different from the usual attitude observed in non-piercing moths and suggests a dorsal linkage which is not very compact on the distal part of the proboscis, allowing fluids to be sucked up in this region apart from the apical aperture of the proboscis. This aspect will be further dealt with under VI. MOUTHPARTS.

C. Preference for different conditions of fruit

Table 1 indicates the preference of individual species to rotten, damaged or sound fruit. Particulars as to how and when the survey was made, is given under III. MATERIAL AND TECHNIQUE. Although some counts were made on plums, apples, grapes and figs, the greater number of counts was made in peach orchards. "Miscellaneous spp." in this table denote all other species, which usually included a majority of Spodoptera and Euxoa species. "Rotten fruit" was taken to be damaged fruit which was very soft and overripe or which had started decaying, either lying on the ground or still on the tree. "Damaged fruit" was taken to be fruit injured by hail, birds and beetles or pierced by piercing moths, either still on the tree or lying on the ground.

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TABLE 1

Preference of moths for different conditions of fruit
(Numbers denote the number of feeding moths)
observed in fruit orchards

	Rotten fruit	Damaged fruit	Sound fruit
Achaea catella Guen.	92	20	
Achaea echo Wlk.	3	2	
Achaea finita Guen.	86	57	
Achaea lienardi Boisd.	4		
Achaea sordida Wlk.	54	34	
Anomis spp.	55		
Anua dianaris Guen.	26	2	
Anua tirhaca Cram.	43	6	
Calpe provocans Wlk.			20
Calpe triobliqua Saalm.			45
Cyligramma latona Cram.	98	3	
Grammodes stolida Fabr.	36	5	
Othreis materna L.			9
Parallelia algira L.	17	2	
Pericyma atrifusca Hmps.		2	171
Pericyma mendax Wlk.		1	12
Pericyma scandulata Feld.	3	5	126
Polydesma quenavadi Guen.	20		
Serrodes partita (Fabr.)	3	6	85
Sphingomorpha chlorea Cram.	374	38	
Ulotrichopus spp.	92	1	
Miscellaneous spp.	916	48	

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When moths were found feeding in a pierced hole that showed a discoloration or that was larger than that made by the initial puncture of piercing moths, these moths were recorded as feeding on damaged fruit. Punctures of piercing moths in peaches often show this discoloration after one day, especially in more ripe fruit. Some cases were observed where moths preferred feeding on the intact half of a peach which was otherwise rotten or bird-eaten. These were recorded as feeding on sound fruit.

The number of fruit in the category "Damaged fruit" was much smaller than in the "Rotten fruit" category. Bearing this in mind it would seem that Achaea spp., Grammodes stolida and Parallelia algira have no preference for either of these two fruit categories. With Anomis spp., Cyligramma latona, Sphingomorpha chlorea and Ulotrichopus spp., however, this is not the case: they show a distinct preference for soft and overripe fruit. None of the species just mentioned were ever recorded feeding on sound fruit.

Of all the moths in Table 1 Calpe spp., Othreis materna, Pericyma spp. and Serrodes partita are the only ones that were seen to pierce and to feed on uninjured fruit. Although the three Pericyma spp. and Serrodes partita had been noticed to feed on fruit in the categories "Rotten fruit" and "Damaged fruit", their relatively high numbers in the category "Sound fruit" suggests strongly that, together with the two Calpe spp., they prefer to feed on fresh undamaged fruit.

D. Preference for different kinds of fruit

Jack (1922) found in Rhodesia that fruit-piercing moths attacked early peaches, plums and figs but that they did "not care for the slightly bitter Willow peaches", while apples received little attention in orchards where there were ripe peaches as well.

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Golding (1945) reported that ripe mangos were more attractive than ripe sweet oranges. In an experiment with suspended mangos, bananas and grapefruit, he found the former to be the most attractive and the latter the least attractive. Since the moths were principally Achaea spp., these results are considered to be biased because, as seen in Table 1, Achaea spp. have not been recorded to feed on intact fruit in this study.

The fruit-piercing moth Serrodes partita in the south-western Cape Province prefers peaches of all deciduous fruit, according to Kriegler (1957). Myburgh (1963) even specified the preference of the moths for the canning peaches Keimoes and Kakamas.

With regard to citrus fruit, Hargreaves (1936) observed that mandarines are preferred to oranges, and oranges to grapefruit, while sweet limes were preferred to any of these. According to Cotterell (1940) all citrus fruits, except lemons and limes, are pierced in the following descending order of preference: tangerine, orange, grapefruit, sour orange. Weddell (1944) found fruit-piercing moths in Australia to attack citrus fruit rather than other tropical and subtropical fruit. The moths concerned were Othreis spp. In the literature the moths belonging to this genus are most commonly quoted as serious pests of citrus.

During field-observations in Italy on Scolyopteryx libatrix, Bänziger (1969) found this species to prefer certain kinds of fruit to others, but this preference seemed to change to other fruits as the season advanced, a change of preference which Bänziger ascribed to a possible optimal ripening stage of fruit. He also found that elderberries (Sambucus sp.) were preferred during a period when a strong odour was noticeable (from the berries?)

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Except for the test by Golding (1945), no experimental data seems to exist on fruit preference by fruit-piercing moths. When studying such preferences, the following factors in an orchard are believed to influence moth numbers: the ripeness of the fruit, the strength of the odour emanating from the fruit, wind direction and difference in distance of the fruit trees from the daytime hiding places. An attempt was nevertheless made to reveal any preferences fruit-piercing moths may have for different kinds of fruit as well as for different cultivars of the same fruit under orchard conditions.

In the first attempt to establish fruit preference, counts of moths were made in the orchard of the University Experimental Farm in which only the following fruit trees, growing close together, bore fruit at the time of the observation: two Satsuma plum trees, two Transvaal Yellow peach trees, three Kakamas peach trees, two Alberta peach trees and one clingstone peach tree of an unknown cultivar. Counts were made on two days only, four days elapsing between the counts. On both evenings the weather was clear, warm and windless. On the first evening counts were made from 21h00 to 22h00 and on the second evening from 20h00 to 21h00. The counts were made as described under III. MATERIAL AND TECHNIQUE and included all moths on the trees and on fallen fruit, whether feeding or not. The results are presented in Table 2.

The low counts on Alberta peaches on the second evening are ascribed to the very few fruit left on the two trees. The high count of miscellaneous species was made mainly on fallen fruit beneath the trees. The Satsuma plums bore the most fruit of all the trees, yet they attracted fewer moths of the "Miscellaneous spp." group compared to the peach cultivars although there was an amount of fallen plums comparable to fallen peaches. A noticably stronger odour emanated from the

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TABLE 2

Preference of moths for different fruits

(Numbers denote moths feeding on fruit)

	13.1.1969 21h00 - 22h00					17.1.1969 20h00 - 21h00				
	Tvl. Yellow peach	Satsuma plum	Kakamas peach	Alberta peach	? (Peach)	Tvl. Yellow peach	Satsuma plum	Kakamas peach	Alberta peach	? (Peach)
Achaea echo							1	1		
Achaea finita			1					1		1
Anua tirhaca		1	2							
Calpe triobliqua	2		2	3	1	1		1		
Cyligramma latona	1	3								
Grammodes stolida	2	3	3				3	5		1
Parallelia algira	1		2		1					
Pericyma atrifusca	3	1	2	1	1		1	2		
Pericyma mendax	4	2	2	2				1		
Pericyma scandulata	3	3	2	2	3	5		1		3
Polydesma quenavadi		3	1				1	2		
Serrodes partita	1									
Sphingomorpha chlorea	1	4	7	1		2	2	1	1	
Ulotrichopus spp.	1	4	4	2			1			
Miscellaneous spp.	105	45	133	24	6	132	65	413	90	27

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peaches, which perhaps in part at least could explain the higher number of moths. Of all the fruit trees, the two Kakamas peaches attracted most moths in numbers and different species on both days, although the counts are low when the "Miscellaneous spp." group is excluded.

A similar second experiment was carried out on 13.2.1969 in the Roodeplaat orchard. The object was to test the preference of free-flying moths for three different clingstone peach cultivars. Three Tokane and two Transvaal Yellow peach trees stood close together, with two Nooiens peach trees about 25 m away. These seven trees stood in an orchard of apricot and other peach trees which did not bear fruit. Between this orchard and the indigenous bush, which was about 110 m away from the orchard, there was a vineyard with fruit and a row of fig trees without fruit. The vineyard and fig trees, however, covered only about half the area between the peach orchard and indigenous bush, the rest of the area being an open vegetable garden.

The Transvaal Yellow trees had few fruit left and these were mostly overripe, emitting a strong smell of peaches. The fruit of the Tokane trees were still relatively green and firm. The weather was clear, warm, windless and very dry. Feeding and resting moths on sound and fallen (few) fruit were counted. The results of the counts are presented in Table 3.

When the total counts of only the piercing moths (Calpe spp., Pericyma spp. and Serrodes partita) on the different cultivars are compared, the result indicates a preference for Nooiens with Transvaal Yellow 18, Nooiens 26 and Tokane 17. The disappointingly low numbers of moths, perhaps due to the serious drought during the two months prior to this experiment, make any definite conclusions impossible.

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TABLE 3

Preference of moths for different peach cultivars

(Number of moths counted on fruit)

	Tvl. Yellow									Nooiens									Tokane								
	20h00-21h00	21h00-22h00	22h00-23h00	23h00-24h00	24h00-01h00	01h00-02h00	02h00-03h00	03h00-04h00	04h00-05h00	20h00-21h00	21h00-22h00	22h00-23h00	23h00-24h00	24h00-01h00	01h00-02h00	02h00-03h00	03h00-04h00	04h00-05h00	20h00-21h00	21h00-22h00	22h00-23h00	23h00-24h00	24h00-01h00	01h00-02h00	02h00-03h00	03h00-04h00	04h00-05h00
Achaea catella	1	2	2				1					1	1								1		1	2	1	1	1
Anua tirhaca		1																						2	1	2	3
Calpe provocans														1	1												
Calpe triobliqua												1		2	1												
Cyligramma latona		1									1	1		1	2	1					1		1	1	1	1	1
Grammodes stolida										1																	
Pericyma atrifusca	2			1	1	1	1			2			2								1	3	2	2		2	
Pericyma scandulata	1	2	2		4	2			1	3	3	5	2	4						1	4	1		1			
Serrodes partita				1													1										
Sphingomorpha chlorea	1	2		1	2	2	3	1	1	1	3	1	3	2	1			1			4	3	1	1			
Ulotrichopus spp.	1	1	2	1			1	1			1	4	5	2													
Miscellaneous spp.	1	2	1	4	6	1	6	3	7	3	3		6	4		3	2	1			3		2	2	3		2

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A third experiment to test fruit preference was carried out on 29.1.1969 at the same site of the previous experiment. Three fig trees were selected from a row of ten, all bearing ripe fruit and being nearest to the adjacent bush (± 60 m). A row of 8 Alphonse Lavalle vines selected for the counts, was situated more or less in the middle of a vineyard of about fifteen rows of different cultivars, many with ripe grapes. Two Nooiens clingstone peach trees, situated in the peach orchard beyond the vineyard and about 110 m from the bush were selected from seven peach trees bearing ripe fruit. The two Nooiens peach trees had approximately the same number of fruit as the three fig trees. The weather was clear, warm and windless with heavy dew.

The results are presented in Table 4. Moths were again counted on fallen and sound fruit while resting or feeding. When the proximity of the fig trees to the bush and the strong odour emanating from ripe and rotting figs is considered, then the greater numbers of all species of moths counted on the fig trees is not surprising.

Remembering, however, that the peach trees were further away from the bush, partly separated from the latter by the fig trees and the vineyard, then the numbers of Cyligramma latona could be significant. The relatively high number of C. latona on the peaches is explained as follows: This species is a weak flyer and the most diurnal of all the noctuids encountered in this study. It may be seen feeding during the day in exposed situations. It is assumed here that the specimens counted were already present from previous days and that they had not left the vicinity of the peach orchard.

The relatively small number of moths on grapes is explained thus:

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TABLE 4

Preference of moths for different fruits

(Number of moths counted on fruit)

	Figs									Peaches									Grapes								
	20-21h00	21-22h00	22-23h00	23-24h00	24-01h00	01-02h00	02-03h00	03-04h00	04-05h00	20-21h00	21-22h00	22-23h00	23-24h00	24-01h00	01-02h00	02-03h00	03-04h00	04-05h00	20-21h00	21-22h00	22-23h00	23-24h00	24-01h00	01-02h00	02-03h00	03-04h00	04-05h00
Achaea catella	3	1					1	3	1		1								1	1	1						
Achaea finita			1																								
Achaea sordida		1									1																
Anua dianaris	1	1	1		3	3	1	2			1									5						1	
Anua tirhaca		1		1	1		1	1					1														
Calpe provocans		1																									
Calpe triobliqua	1	1			1	1									1												
Cyligramma latona	1	3	4	3	2	1	1	1		4	3	3	1	2	1	1		2								1	
Grammodes stolida	1				1		1				1																
Hypanua sp.			1	2	2	1	1																		1		
Parallelia algira	1			1																1							
Pericyma atrifusca	1			1	2	1		1		1	1		1	1	1												
Pericyma scandulata	7		1		1								3	1						1	1						
Polydesma quenavadi	2	2	3	1	2																						
Serrodes partita				1																							
Sphingomorpha chlorea	12	19	16	10	11	8	5	4	7	3	1	1	2	1					3	2	1		2	2			
Ulotrichopus spp.	7	4	3	1	3	3	3	2	3			2		1	1				1	2	1		1	1			
Miscellaneous spp.	62	50	61	14	17	41	44	67	57	4	4	1		2	2				32	22	16	7	8	6	3	7	5

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(i) There were few damaged grapes for non-piercing moths to feed on.

(ii) The row of vines selected for counting ran through the middle of the vineyard.

(iii) The vineyard had at some stage been sprayed against anthracnose with Bordeaux mixture. These reasons nevertheless remain speculative because the overall numbers of counted moths are low.

E. Incidence of moths throughout the night

Although several authors claimed that the main period of fruit-piercing moth activity is during the first half of the night (Tryon, 1924; Baptist, 1944; Kriegler, 1957; Neubecker, 1966), no counts of moths had been made throughout the night by these authors. Golding (1945) recorded the species seen on fruit at various intervals during the night, but no actual counts were made. King and Thompson (1958) "observed moths to be active only during the night from about 8.30 p.m. to 3.30 a.m." According to Whitehead & Rust (1972) fruit-piercing moths are present from 19h30 to 01h00. They state that "counts made at regular intervals indicated that Serrodes partita moth populations were relatively stable from 20.30 to 23.30 hours."

Tables 3, 4 and 5 give hourly counts of moths throughout the night in three separate experiments. The experiments in which the results for Table 3 and 4 were obtained, have already been described in the previous section D. The counts presented in Table 5 were made on 19.2.1971 in fine weather on a single Transvaal Yellow peach tree, the only tree in the orchard on the University Experimental Farm left with fruit late in the season. This partly explains the large number

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TABLE 5

Incidence of moths throughout the night of 19-20.2.1971

(Numbers denote feeding moths. Numbers in brackets denote non-feeding moths)

	19-20h00	20-21h00	21-22h00	22-23h00	23-24h00	24-01h00	01-02h00	02-03h00	03-04h00	04-05h00	05-06h00
Achaea catella	4	3	3	5 (3)	3 (3)	3	6 (1)	8 (1)	4 (1)	3	2
Achaea finita	13	10	20 (3)	20 (3)	12 (7)	16 (5)	34 (5)	23 (10)	29 (6)	26 (5)	20 (3)
Achaea sordida	9	10	10 (1)	4 (2)	4 (1)	8 (4)	11 (5)	6 (2)	8 (3)	7 (3)	4 (5)
Anua tirhaca					(1)	(1)	(1)	1			
Calpe thriobliqua	1	2	2	1 (1)	1	1 (1)	1	(1)			
Cyligramma latona	1	1	1	1	1	(1)	1	(1)	(1)	(1)	(1)
Grammodes stolida	1	1									
Parallelia algira			1	1	(1)	1	1	2			
Pericyma atrifusca	1			1							
Pericyma mendax		1	(1)					1	1	(1)	(1)
Serrodes partita		1	1	2	2	1 (1)	1	1	1		
Sphingomorpha chlorea	4	3	6	6 (1)	4 (3)	6	5	5 (1)	5	4	2
Miscellaneous spp.	11	11	10 (5)	20 (3)	19 (2)	23 (4)	14 (6)	7 (7)	15 (3)	12 (3)	8 (2)
Relative Humidity (%)	70	73	76	79	82	86	89	92	95	97	98
Temperature (^{o}C)	21	20	19	18,5	18	17	16	15	14	13,5	15

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of moths. Moths feeding and resting on fruit were counted separately. Fallen fruit had been removed.

The numbers in brackets in Table 5 denote resting moths, that is, not actively feeding. This feature is included to show that active feeding does occur throughout the night.

Table 6 gives the hourly totals of all the moths in Table 5, the hourly totals for Tables 3, 4 and 5 combined and the latter totals excluding the "Miscellaneous spp." The results reveal the following general trend: Greatest moth activity occurs during the first three hours after dark, followed by a small decrease in numbers around midnight. The number of moths increases again at about 01h00 and this number is maintained until 04h00.

In Table 5 this second period of increased activity actually shows the greatest number of moths. This has a bearing on the hours of illumination of the perimeters of orchards to repel fruit-piercing moths. Myburgh & Whitehead (1971) recommended having the lights on before dark until after midnight. Bosch (1971a) effectively controlled attacks of Calpe spp. on grapes by reducing the damage to 1,5% when she illuminated vineyards for 12 hours a night.

Because the piercing moths in Table 6 (Calpe spp., Othreis materna, Pericyma spp. and Serrodes partita) were poorly represented in the counts or not at all, more reliable data about the feeding activities of these moths throughout the night will be necessary.

F. Constancy of moths visiting a source of food

Tryon (1924) maintained that Othreis spp. may occur at night in the same spot during a period of several days and

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TABLE 6

Incidence of moths throughout the night

(Numbers denote feeding and resting moths counted on fruit)

	20-21h00	21-22h00	22-23h00	23-24h00	24-01h00	01-02h00	02-03h00	03-04h00	04-05h00
Totals for Table 5	43	64	74	64	76	92	77	77	65
Totals for Tables 3-5	209	218	226	148	176	187	162	181	158
Totals for Tables 3-5 excluding miscellaneous spp.	128	144	137	103	118	121	92	91	76

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Myburgh (1963) declared that fruit-piercing moths appear in the same or in other orchards on subsequent nights. Whitehead & Rust (1967) studied marked moths in orchards at night and found that moths did not feed in the same orchard on following nights. The method used for marking and the numbers of moths marked were not given.

When vineyards at Groblersdal, Transvaal, were investigated during the 2nd to 4th December 1963 after reports of damage by fruit-piercing moths had been received, large numbers of Sphingomorpha chlorea and fewer Calpe provocans were found. Surveys made on the 11th and 12th of the same month in the same vineyards did not reveal a single specimen of any of the two species, despite the fact that no apparent changes in the weather or the vineyards had taken place. Only very few Achaea catella were seen.

The above reports show differences in the behaviour of moths in orchards, which may partly be explained by observations made by Bosch (1970). She described different patterns of moth damage in fruit-growing areas of Rhodesia. Damage may occur every year throughout the season due to a resident moth population which has established a permanent breeding ground in the area. Damage may also be due to migrant moth populations which may establish temporary breeding grounds in the vicinity of an orchard.

The constancy of fruit-piercing moths visiting a particular source of food appears to depend on several factors e.g. whether or not a species is migratory, the geographical location of the orchard, the time of the year, the age and physiological state of a moth, the presence of bush near the orchard in which to hide or to breed and possibly the attractiveness of the fruit (own conclusions).

A study with marked moths was undertaken during February

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1971 in the orchard on the University Experimental Farm. The same single Transvaal Yellow peach tree, on which moths were counted for the data in Table 5, was used in this study.

Moths were caught on the fruit, transferred to a wood and wire gauze cage, anaesthetized together as a group with ethyl-ether, marked individually and then left together in the opened cage near the peach tree the same evening (15.2. 1971). Two hours after having been placed near the tree (at 24h00), the moths had not left the cage. Inspection of the cage at 08h00 the next morning revealed that one moth had remained.

Moths were then caught by hand the same evening and immediately marked without anaesthetizing them and then released. By this method more moths were caught and marked. Of the totals given in Table 7 of moths marked on 15.2.1971, only the following numbers were anaesthetized before marking: one Achaea catella, nine A. finita, seven A. sordida and two Sphingomorpha chlorea.

A second group of moths was marked on 19.2.1971 with a different colour to that used for the first group. The peach tree was searched for marked moths twice on an evening, at 19h30 and at 22h00 until 26.2.1971. The weather during the days of observation was dry and warm to hot throughout, except on 20.2.1971 when there was a heavy rainstorm from 18h15 to 21h45.

The number of unmarked moths remained high during the first days of the experiment and then diminished only gradually. Unmarked moths were only counted on two evenings. The dates when unmarked moths were counted and the number of moths are as follows: 16.2.1971 no Achaea catella, thirty two A. finita, thirty A. sordida, two Sphingomorpha chlorea as

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TABLE 7

Recovery of marked moths

(Numbers in the table denote the number of recovered moths. The first group was marked and released on 15.2.1971 and the second group on 19.2.1971)

	No. marked and released	15.2.71		16.2.71		17.2.71		18.2.71		19.2.71		20.2.71		21.2.71→26.2.71
		19h	22h	19h	22h	19h	22h	19h	22h	19h	22h	19h	22h	
Achaea catella	2													
Achaea finita	44		2	3	3	1	1			1	1	STORM		
Achaea sordida	40		1	3	2									
Sphingomorpha	6			1										

	No. marked and released					
Achaea catella	2					
Achaea finita	40		3	STORM		
Achaea sordida	25		1			
Sphingomorpha	7				1	

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well as two Anua tirhaca, one A. dianaris, one Calpe triobliqua, one Serrodes partita and miscellaneous smaller moths. 20.2.1971 Counts were made at 20h00, after the storm. No Achaea catella, four A. finita, one A. sordida, two Sphingomorpha chlorea and a few miscellaneous smaller moths.

The results, presented in Table 7, show that a small percentage of moths returned to the same source of food on subsequent nights, although there was no other fruit known of in the area to serve as alternative food source and although the weather was uniform throughout except for one rainstorm. The longest period to elapse between marking and subsequent recording was 4 days for a single Achaea finita.

G. Predators

A specific behaviour of moths while feeding in an orchard could possibly be related to bat activity: At times, without apparent cause, all the moths simultaneously scattered out of a tree in what may be called an alarm reaction. It is not known whether this reaction was the result of ultrasonic pulses emitted by bats (Roeder, 1966). Often bats were observed flying through orchards and close to trees full of moths, without the latter reacting in any recognisable way.

Moths feeding on fallen fruit were often devoured by toads, which were found to be active under fruit trees from the early evening until 02h00 to 03h00. Large Achaea spp. were devoured with ease even by halfgrown Bufo carens Smith.

Arthropod predators of fruit-piercing moths that were encountered in the two study orchards were theridiid spiders (near Latrodectus) which caught only smaller moth species in their irregular webs and large mantids, capable of holding large strong moths like Sphingomorpha chlorea.

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V. CAGED MOTHS

Experimental data on caged moths to test their ability to pierce different kinds of fruit, is scant. The ability of fruit-feeding moths to pierce fruit of varying hardness has not been tested in the past. In the following experiments with caged moths, an attempt was made to obtain more information on the aforementioned aspects.

A. Tests

Before caged moths were used in experiments, they had unrestricted access to soft juicy peaches that were cut into pieces. This was to ensure that the moths lived at least three days, the minimum period almost all caged species were able to survive without food after having fed well.

The peaches used in the experiments were placed in the cages at dusk and removed as soon as possible after having been pierced to be tested for their hardness. This was done either during the evening or the following morning.

To test their piercing ability, moths were first given soft ripe fruit with intact skin. If they were unable to penetrate the fruit with their proboscis, then pared fruit of varying hardness was provided. An exception was made with those species that had been observed to feed on intact fruit in orchards (see Table 1, p. 23). From the start they were given firm fruit of various degrees of ripeness and with intact skin.

Where moths were capable of piercing the intact skin of fruit, the paraffin wax was peeled from the fruit and the pressure tested on the cheeks exposed to the moths, but away from the pierced area, or on the opposite cheek. No differ-

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ences were found in pressure tests on surfaces of the same fruit that had had a wax covering and those that had not.

In the case of pared fruit the pressure tests were performed as follows: If the pared area was not penetrated by a proboscis, although moths had been seen trying to do so, this same area was used for the test. If it had been penetrated and not just palpated, another area on the same cheek was pared and tested.

After it had been noticed in an experiment with pared fruit that some of the latter had been pierced, it was removed and subjected to the pressure test. In this way the moths were forced to feed on the pared surfaces of harder fruit. The transition stage in hardness of the pared fruit could thus be determined, that is, the range where moths were just able to penetrate the fruit flesh with their proboscis.

The number and species of moths and the variety of fruit tested, was determined by the availability of material during the period January - March 1971 when the tests were conducted.

Longevity of caged moths could be correlated with their ability to pierce the fruit flesh with their proboscis. Almost all moths that were unable to do so died after three days, although they tried unsuccessfully to feed on the pared surfaces. Moths capable of penetrating the fruit flesh with their proboscis and thus being able to feed on the released juice, invariably stayed alive a week or longer. Longevity was, however, not used as a criterion in these experiments.

Each moth species used in the tests will now be discussed individually. The number of moths used in the test as well as the type of fruit is stated. The numbers in the columns

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of the tables represent the readings on the pressure tester (pounds, using a 5/16" plunger) and each reading represents a single determination and was made on a different fruit.

B. Results

1. Moths that can pierce the skin of fruit

From orchard observations it was obvious that some moth species preferred feeding on intact fruit (see also Table 1, p. 23). These species were given firm unpared peaches right from the start in the cage experiments.

Calpe provocans Wlk.

This species easily pierced intact peaches. Three tests with 5, 1 and 3 moths respectively were performed with three cultivars.

TABLE 8

Pressure tests of sound fruit pierced by C. provocans

(Numbers denote values in pounds obtained with a USDA fruit pressure tester)

Kakamas peach	Keimoes peach	Freestone Nectarine
20,1	29,0	29,8
21,2	>30,0	>30,0
21,5		
22,7		

Calpe triobliqua Saalm.

Two peach cultivars were tested separately, each with 3 moths as follows:

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TABLE 9

Pressure tests of sound fruit pierced by C. triobliqua

(Numbers denote values in pounds obtained with a USDA fruit pressure tester)

Transvaal Yellow peach	Freestone Nectarine
25,5	9,3
26,0	10,8
>30,0	
>30,0	

Pericyma atrifusca Hmps.

Two unpared clingstone peach cultivars were pierced in two tests, each with 3 moths.

TABLE 10

Pressure tests of sound fruit pierced by P. atrifusca

(Numbers denote values in pounds obtained with a USDA fruit pressure tester)

Transvaal Yellow peach	Tokane peach
16,5	26,6
17,0	27,0

Pericyma mendax Wlk.

A single moth pierced the two peach cultivars submitted to test.

TABLE 11

Pressure tests of sound fruit pierced by Pericyma mendax

(Numbers denote values in pounds obtained with a USDA fruit pressure tester)

Freestone Nectarine	Keimoes peach
>30,0	25,8
>30,0	26,2

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Pericyma scandulata Feld.

These moths did not feed readily when caged. A few individuals did nevertheless pierce unpared peaches conforming to the pressure test values set out below.

TABLE 12

Pressure tests of sound fruit pierced by P. scandulata

(Numbers denote values in pounds obtained with a USDA fruit pressure tester)

Kakamas peach
20,0
21,2
21,5
22,7

Serrodes partita (Fabr.)

Even when unpared peaches were quite green and hard, Serrodes easily pierced them. Two tests with 2 and 3 moths respectively were made.

TABLE 13

Pressure tests of sound fruit pierced by Serrodes

(Numbers denote values in pounds obtained with a USDA fruit pressure tester)

Keimoes peach	Freestone Nectarine
28,0	27,5
28,3	28,2
	>30,0
	>30,0

Freshly pierced holes in unpared peaches with firm flesh appear kidney or bean shaped. In soft fruit they tend

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to be oval to round. This was observed with the naked eye on the fruit used in the tests with caged moths.

Many holes (not counted) were pierced in intact fruit by relatively few caged moths. It does appear that these piercing species do not use the same feeding holes again once they have retracted their proboscis, at least under laboratory conditions. One specific example only can be quoted: Three Pericyma atrifusca moths caged with one wax-covered Tokane peach, pierced 23 holes into the exposed area of 2 cm^2 in one night.

2. Moths unable to pierce the skin of fruit

Moths considered under this heading were not able to pierce the skin of different kinds of soft ripe fruit which are mentioned under each moth species. The following moths in this category were tested: Achaea catella, A. finita, A. sordida, Anua tirhaca and Sphingomorpha chlorea.

Achaea catella Guen.

Two kinds of fruit were tested in two experiments, using 6 and 5 moths respectively.

TABLE 14

Pressure tests of pared fruit exposed to Achaea catella

(Numbers denote values in pounds obtained with a USDA fruit pressure tester. Fruit marked ✓ was penetrated by the proboscis. Fruit marked * could not be penetrated)

Keimoes peach	Wicksen plum
<3,0✓	3,0✓
3,0✓	3,3✓
3,5✓	4,0*
4,5*	
9,5*	

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Achaea finita Guen.

This species was unable to feed on well-ripened but intact Satsuma plums, Alphonse Lavalle grapes and pears of an unknown cultivar used in a test with fifteen moths. Only one test was performed with pared fruit, using one peach cultivar and 6 moths. The one fruit marked "uncertain" in Table 15 did not show the typical spongy feeding areas, although surface feeding had taken place and the flesh showed pits about 2 mm deep.

TABLE 15

Pressure tests of pared fruit exposed to Achaea finita

(Numbers denote values in pounds obtained with a USDA fruit pressure tester. Fruit marked ✓ was penetrated by the proboscis. Fruit marked * could not be penetrated)

Transvaal Yellow peach
4,0✓
4,6✓
5,5✓
6,5 uncertain
8,5*
8,8*
10,0*

Achaea sordida Guen.

This species was unable to feed on well-ripened but sound Satsuma plums and Alphonse Lavalle grapes in a test with 5 moths. Using pared Transvaal Yellow peaches, 6 moths were tested once.

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TABLE 16

Pressure tests of pared fruit exposed to Achaea sordida

(Numbers denote values in pounds obtained with a USDA fruit pressure tester. Fruit marked ✓ was penetrated by the proboscis. Fruit marked * could not be penetrated)

Transvaal Yellow peach
3,3✓
4,2✓
4,7✓
5,0✓
5,4✓
8,8*
9,1*

Anua tirhaca Cram.

One test only was performed with 5 moths and four pared peaches.

TABLE 17

Pressure tests of pared fruit exposed to Anua tirhaca

(Numbers denote values in pounds obtained with a USDA fruit pressure tester. Fruit marked ✓ was penetrated by the proboscis. Fruit marked * could not be penetrated)

Keimoes peach
<3,0✓
3,1✓
3,5✓
6,0*

Sphingomorpha chlorea Cram.

This species was unable to feed on well-ripened but in-

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tact Satsuma plums, Alphonse Lavalle grapes and pears of an unknown cultivar, neither was it able to pierce any of the pared fruit used in the tests. Moths were observed to feed on the pared surfaces with the distal portion of the proboscis held flat down (Fig. 1d), but never were piercing attempts observed. Twelve and thirteen moths were caged with four ripe peaches and three very ripe plums respectively.

TABLE 18

Pressure tests of pared fruit exposed to Sphingomorpha

(Numbers denote values in pounds obtained with a USDA fruit pressure tester. Fruit marked * could not be penetrated by the proboscis)

Keimoes peach	Wicksen plum
<3,0*	3,0*
3,0*	3,3*
4,5*	4,0*
5,0*	

The results of the fruit pressure tests are discussed in parts A and B of VII. DISCUSSION in relation to orchard studies, to the structure of the proboscis and to views expressed in literature.

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VI. MOUTHPARTS

In the two preceding chapters it was shown that fruit-feeding moths have a preference for different conditions of fruit in orchards and that, in tests with caged moths, these moths could be separated into two groups: those that could pierce the intact skin of fruit and those that were unable to do so. A morphological study of the probosces of fruit-feeding moths would show whether there is any correlation between the ability of a moth to pierce fruit and the structure of its proboscis.

A general morphological description of the essential features of the Lepidoptera proboscis as seen in the fruit-feeding noctuids is first given. Probosces of some species of the fruit-feeding moths are then considered individually and the salient features in which they differ from the general description or between other species are pointed out.

A. General description of the proboscis

The proboscis differs little in its structure except for the short base and the distal or apical region. The greater part of the proboscis (between the basal region and apical region) is called the intermediate region for convenience of description. The general description of the proboscis is based on this intermediate region. After this general description, the differences between it and the basal and apical regions are discussed.

The tapering suctorial proboscis is composed of the two tubular and terminally closed galeae which fit together firmly. Through their union their concave mesal walls form the cylindrical food channel (Fig. 3, f. chl.).

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In the fairly uniform intermediate region of the proboscis, the outer wall of each galea consists of flexible endocuticle (Fig. 3, enc.) overlain by exocuticular ribs (Figs. 3-12, exc. rib) at regular intervals. They coalesce or fork and do not reach the mesal wall dorsally or ventrally. On and between the ribs exocuticular sensilla chaetica (Figs. 3-12, sens. chaet.) and sensilla basiconica (Figs. 3-12, sens. bas.) occur irregularly arranged. These two types probably represent the "galeal sensilla" of Swart (1969).

In the dorsal and ventral strips of endocuticle between the ribs and the mesal wall, small distally directed exocuticular spikelets (Figs. 3, 12, spk.) occur. Ventrally they continue from the basal region distally to the apical region. Dorsally, however, they are found only in the basal region and in the proximal part of the intermediate region.

The mesal wall of the galea consists of closely arranged exocuticular bars (Figs. 3, 12, exc. bar) which are present from the base of the galea to its apex except at the extreme tip. The bars continue dorsally to form the longitudinal dorsal bar (Fig. 3, d. bar) and distally directed plates (Figs. 3, 8, 10, 12, plt). Ventrally the bars form processes each of which consists of a tooth (Fig. 3, th.) and a hook (Fig. 3, hk.). The plates on each galea lie close together to form an apparently continuous band or ribbon. The band (Fig. 8, bd.) of one galea overlies the band of the other and thus they constitute the dorsal linkage or closure of the food channel. In the apical region, however, the plates are enlarged and separated. A second row of pointed, elongated and distally directed plates appears above the first. These plates (the "linking denticles" of Bänziger, 1970) from both galeae overlap each other. The interlocking curved teeth and hooks create a very rigid though moveable ventral linkage.

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The rod-like exocuticular dorsal bar stretches from the galeal base to where the dorsal linkage ends distally. This dorsal bar gives the proboscis the ability to coil when at rest (Eastham & Eassa, 1955; Swart, 1969).

Stout, well-developed exocuticular sensilla basiconica or "channel pegs" (Kirbach, 1884) (Figs. 3, 12, chl. peg) project into the food channel from the mesal walls of the galeae. These are the "modified trichoid sensilla" of Swart (1969). They are arranged irregularly, but are present in greater numbers in the basal and apical regions of the galeae.

The basal region of the proboscis is anteriorly continuous with the intermediate region so that there is no clear boundary between these two regions. A basal region can nevertheless be distinguished because the proboscis widens laterally and is compressed dorso-ventrally, and because numerous spikelets and some long sensilla trichodea are present. The basal region also does not coil.

As pointed out by Swart (1969) it is difficult to detect the transition from the galeal base to the stipes. Laterally at least there is a well-defined demarcation by a heavily sclerotized girdle, corresponding to Srivastava's (1957) "girdle-like thickening" in Papilio demoleus L. and the "oblique transverse fissure" of Srivastava & Bogawat (1969) in Othreis materna.

The exocuticular ribs in the basal region are characterised by the presence of numerous distally directed spikelets on their distal sides. More proximally the ribs gradually shorten dorsoventrally and become faint, but the rows of spikelets remain.

At the base of the proboscis the food channel is open

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dorsally and overlain by the labrum (Eastham & Eassa, 1955; Swart, 1969). A few long sensilla trichodea and shorter sensilla chaetica occur on the outer wall of the basal region and the proximal part of the intermediate region.

The apical region of the proboscis is primarily characterised by the presence of greatly enlarged sensilla, modified into blades, hairs and barbs. The ribs gradually shorten from the dorsal side in the proximal part of the apical region until only very short ribs remain ventrally on the galeal apices (Figs. 8-12). The exposed endocuticle without ribs bears the blades and hairs. At the extreme tip the ribs and the dorsal and ventral linkage mechanisms are absent. Minute sensilla basiconica and sensilla chaetica occur everywhere on the outer wall of the galea in the apical region.

Breitenbach (1882) showed that the modified sensilla or so-called "sap borers", used for lacerating nectariferous tissue and fruit flesh, were all derived from a simple hair-type sensillum. The chitinous base of the latter, named "cylinder" by Breitenbach (Figs. 4-12, cy.), is bigger and more elongated in some species, assuming various forms. He designated the part corresponding to the hair the "central mass" (Figs. 4-12, c.m.) in the modified structures. In some species he noted the distal part of the central mass ended in a round tip crowned with a "point", all being part of the central mass. This "point" is now designated the papilla (Figs. 5-12, pap.) of the modified sensilla.

Although these "sap borers" have the same origin, they have different functions, they display various forms and they are found in certain positions on the proboscis tip in fruit-feeding noctuids. For the sake of convenience they are divided into the following main types:

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1. Galeal blades (Figs. 3-12, gl. bld.). These modified sensilla are elongated, flattened and well sclerotized. Distally they may end in a single sharp or blunt tip, or in two sharp tips. The central mass ends in a papilla except in Calpe, Othreis and Pericyma (Figs. 4, 5, 7) where a definite papilla is absent. Galeal blades occur in any position in the apical region of the proboscis except at the extreme tip. The galeal blades are the same structures as the "erectile barbs" of Bänziger (1970), who found that in Calpe they are erected by blood pressure and aid in the penetration of the proboscis into fruit pulp. Not in all fruit-feeding noctuids, however, are they erected backwards to act as barbs and the name "galeal blades" given by Swart (1969) is thus retained.

2. Galeal hairs (Figs. 3-9, 11, gl. hr.). They are only found on the dorsal side of the proboscis where the hairs from one galea cross the hairs of the other galea to form a brush over the dorsal linkage. This galeal brush (Fig. 3, gl. br.) is a prominent feature in those species where it occurs. The hairs are flattened, thin and do not show any central mass, although a papilla may still be present. Dorsally they end in one or two usually pointed tips. Bänziger (1970) designated them "rasping spines" in Calpe.

3. Galeal barbs (Figs. 4-7, gl. brb.). The barbs are found only in oval depressions on the strongly sclerotized outer walls of the proboscis tip. They are squat, heavily sclerotized and directed proximally. In some species a central mass with papilla may be observed with some difficulty. Swart (1969), who designated these barbs "galeal spines", proved that in Serrodes partita they are elevated during feeding although they are not voluntary moveable. Bänziger (1970), who calls them "tearing hooks", found them firmly fixed in Calpe thalictri Bkh. Because of their form and function,

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the more appropriate designation "barb" is preferred in this study. (See B.5 and C. of Chapter VII. DISCUSSION.)

4. Sap borers. This name, first proposed by Breitenbach (1882), is used here for all other types of modified sensilla which are not flattened, but cylindrical or conical. Around their perimeter they may carry thin ridges ending in pointed tips. The central mass with papilla is well defined. They occur anywhere in the apical region of the proboscis. Some of these sap borers of various Lepidoptera are depicted by Breitenbach (1882) and Kirbach (1884), including the transitional forms. Various types found in the Noctuidae are described by Taylor (1957) e.g. as "dentate papillae", "saw-like setae" and "stout papillae". Of the proboscis examined in this study, only Achaea spp., Anua spp. and Parallelia algira have modified sensilla which are classified under "sap borers", namely their "galeal tubercles" (Figs. 8, 9, 11, gl. tb.).

B. Description of the proboscis of individual species

1. Moths able to pierce the intact skin of fruit

Calpe provocans Wlk. (Fig. 4)

The channel pegs in the apical region are much shorter than further proximally. Their numbers vary from 25 to 39 in the five galeae examined. In the apical region there is only a single row of plates (Fig. 3, plt.). These plates are not elongated or obviously separated from each other. The mesal wall narrows considerably in the apical region compared with the intermediate and proximal regions. Teeth and hooks are more strongly developed in the apical region.

A galeal brush is formed by two rows of hairs as depicted.

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The origin of the thin and delicate hairs of the two species studied in this genus is difficult to detect. The hairs of the one row seem to be modified sensilla intermediate in shape between the hairs of the other row (left in Fig. 4) and the blades. The thin ribbonlike structures could be processes of the cylinder. The ribs do not shorten and blades appear anywhere between them. The blades vary from 55 to 62 in number in the five galeae examined. They are of a type similar to those found by Breitenbach (1882) in Scolyopteryx libatrix L. where the tip or papilla of the central mass extends beyond the cylinder and becomes enlarged and sclerotized.

Each of the 8 barbs per galea has a strongly sclerotized elevation distally on the rim of the depression in which it is seated. The barbs only show a faint outline of what probably represents the central mass.

The galea ends in a sharply pointed and strongly sclerotized tip.

Calpe triobliqua Saalm.

The galeae are very similar to those of C. provocans. The number of channel pegs varies from 24 to 27 and the blades from 53 to 57 in six galeae examined. Of the 8 barbs the most distal one is well anchored and probably immovable.

Pericyma atrifusca Hmps. (Fig. 5)

The channel pegs are shorter in the apical region and their numbers vary from 23 to 29 in nine galeae examined. The food channel is much narrower in the distal region than in the rest of the galea.

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The drawing of part of a rib with sensillum (Fig. 5) was made from a fresh untreated galea. In cleared and stained specimens the ribs appear entire and even.

The dorsal linkage in the apical region consists of a single row of enlarged plates (not shown in Fig. 5). The teeth and hooks are larger in the apical region than in the rest of the galea.

Three rows of hairs per galea form a galeal brush.

In the apical region a gradual transition takes place from clearly defined ribs with endocuticle between them to the complete exocuticular covering of the galeal tip in the region of the barbs. The barbs are implanted in a depression outlined by a heavily sclerotized rim. The 17 to 19 barbs per galea have a discernible papilla. The galeal tip is pointed and heavily sclerotized.

The 37 to 48 blades per galea have blunt tips and there are no external papillae.

Pericyma mendax Wlk.

The galea is very similar to that of P. atrifusca. The number of channel pegs varies from 23 to 27, blades from 43 to 48 and barbs from 25 to 27 in six galeae seen.

Pericyma scandulata Feld.

The galea is very similar to that of P. atrifusca. The number of channel pegs varies from 23 to 28, blades from 34 to 37 and barbs 16 to 19 in five specimens.

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Serrodes partita (Fabr.) (Fig. 6)

The number of channel pegs per galea varies from 21 to 29 in five galeae examined. The food channel in the apical region is much narrower in relation to the diameter of the proboscis than in the intermediate and basal regions.

Two rows of plates are present in the apical region, and possibly a third: in some specimens thin pointed structures were faintly discernible.

Ventrally the very short ribs are found up to the most distal tooth and hook. The enlarged drawing of part of a rib shows the exocuticle (stippled) as seen on a fresh untreated galea.

Each of the 26 to 28 barbs per galea rests in a strongly sclerotized depression and the papilla is faintly recognizable. The pointed galeal tip is heavily sclerotized.

The 60 to 65 blades per galea have the papilla of the central mass protruding on the side. A dense galeal brush is present.

Othreis materna L. (Fig. 7)

The very strongly sclerotized food channel has shallow depressions in the apical region to accommodate the channel pegs which number 28 to 36 per galea in three galeae examined. The food channel in the apical region of the proboscis is much narrower than in the rest of the proboscis.

A single row of plates is present throughout. The two rows of hairs form a thin brush along the entire dorsal surface of the proboscis, although the hairs are wider spaced further proximad.

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In the apical region there is a gradual transition from clearly defined ribs with endocuticle between them towards the solid exocuticular covering of the galeal tip. Shortened ribs, however, remain on the ventral side of the galeal tip (not shown in Fig. 7) and are found up to where the ventral linkage ends. The ribs in the basal and intermediate regions are not entire throughout but "broken" ventrally, forming an angle where the two parts meet. Thus in a cross section of the galea, its ventral side does not appear rounded but somewhat V-shaped. In Fig. 7 the two parts of a rib at their point of joining are depicted ("broken exoc. rib"), as seen in a fresh untreated galea.

The ribs of the galeae in Othreis also differ from all other moths examined in that they are not placed vertically to the longitudinal axis of the proboscis, but obliquely. On the latero-dorsal side of the galea each rib has an inwardly directed process, probably an apodeme for the attachment of a muscle (Fig. 7, "apodeme"). Opposite these apodemes there is also an inwardly directed ridge all along the strongly developed dorsal bar. This ridge may possibly have the same function as the apodemes on the ribs.

The 11 to 15 short sharp blades per galea show no central mass nor papilla. One specimen examined had blades thicker than depicted in Fig. 7 and a central mass was discernible (sexual dimorphism?).

Distad to each of the 7 to 8 barbs, of which the one nearest to the tip is firmly fixed and immovable (Fig. 7, immovable brb.), there is a strongly sclerotized elevation. In the four lateral barbs these elevations have developed into ridges (Fig. 7, "exc. ridge"), two of which end in projections pointing in an opposite direction to the barbs. The two sclerotized projections nearest to the galeal tip probably

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represent the fused barbs and their exocuticular elevations. The central mass and papilla are faintly recognizable in the barbs.

The galea terminates in a pointed and strongly sclerotized tip.

2. Moths unable to pierce the intact skin of fruit

Achaea finita Guen. (Fig. 8)

The 28 to 30 channel pegs in the four proboscis examined vary in length.

In the apical region the dorsal linkage consists of three rows of enlarged and separated plates. The plates of the third row are thin and delicate and not easily discernible.

The irregular distribution of the sensilla chaetica and basiconica on the ribs and between the blades is shown in Fig. 8. Shortened ribs extend nearly to the extreme tip which is lightly sclerotized. On the ventral side of the tip there are two short stout sap borers or galeal tubercles (Fig. 8, gl. tb.).

The 58 to 60 galeal hairs, which possess papillae, do not form a definite brush.

Each one of the 55 to 59 blades has a papilla on its rounded tip. The few short most distal blades are slightly stout and not as flattened as the rest of the blades.

The teeth and hooks of the ventral linkage are larger towards the tip compared to the rest of the galea.

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Achaea catella Guen.

The galea is very similar to that of A. finita. The number of channel pegs varies from 27 to 32, hairs from 56 to 65, blades from 58 to 62 and there are 2 tubercles on each of the three galeae examined.

Achaea echo Wlk.

The galea is very similar to that of A. finita. The number of channel pegs varies from 29 to 32, hairs from 57 to 58, blades from 53 to 60 and there are 2 galeal tubercles on each of the four galeae studied.

Achaea lienardi Boisd.

The galea is very similar to that of A. finita. The number of channel pegs varied from 27 to 32, blades from 50 to 55 and there were 56 hairs and 2 galeal tubercles in each of the three galeae studied.

Achaea sordida Wlk.

The galea is very similar to that of A. finita. The number of channel pegs varies from 26 to 31, hairs from 52 to 57, blades from 42 to 50 and there are 2 galeal tubercles in each of the five galeae examined.

Anua dianaris Guen. (Fig. 9)

The morphology of the galea of this species is in many respects similar to that of Achaea finita. The number of channel pegs varies from 24 to 33 per galea in four galeae

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examined. The apical region has two rows of enlarged plates. Shortened ribs extend to just proximad of the two ventral galeal tubercles. The pointed but somewhat blunt tip is sclerotized.

Most of the 43 to 52 galeal blades occur on the endocuticular area exposed by the shortened ribs. About a third of the proximal blades arise between the ribs. Each blade has a papilla between two rounded tips. The short blades at the tip of the galea are not flattened and are intermediate in form between the depicted enlarged blade and tubercle.

The variations in the types of hair are shown in the figure. The hairs are without a central mass or papilla.

Anua tirhaca Cram.

The galea is very similar to that of A. dianaris. The number of channel pegs varies from 31 to 33 and the blades from 84 to 98 in the four galeae examined.

Grammodes stolida Fabr.

In general the galea of this species resembles that of Anua dianaris (Fig. 9). The 24 to 31 blades in three galeae examined and the two tubercles are similar to those in A. dianaris. The galeal hairs are broader and in some a papilla is visible. The tip of the galea is blunter and less sclerotized than in Anua. The channel pegs number 25 to 29.

Sphingomorpha chlorea Cram. (Fig. 10)

When compared to all the aforementioned species, the diameter of the food channel is very large relative to the

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proboscis diameter. The large channel pegs vary in number from 28 to 32 per galea in the five galeae examined. Two rows of enlarged plates are obvious in the apical region.

The tip of the galea ends in a spoon-shaped endocuticular flabellum (Fig. 10, flb.) which shows only very little sclerotization.

There are from 89 to 102 galeal blades. Each blade ends in a papilla between two sharp tips. Dorsally the blades occur in pairs. The six proximal pairs arise between ribs.

Shortened ribs extend to the base of the flabellum. The enlarged rib in Fig. 10 shows the exocuticle of a rib (stippled) as seen on a fresh untreated galea.

Galeal hairs are absent.

Parallelia algira L. (Fig. 11)

The galea is similar to that of Achaea finita in Figure 8.

Each galea has 24 to 31 channel pegs in the four galeae examined. The ribs are shortened as shown. On the ventral side of the not too heavily sclerotized blunt tip are 2 galeal tubercles.

In the proximal and intermediate regions the plates are small and the band or ribbon narrow. The apical region, however, has two rows of enlarged plates.

There is only a single row of very flat but wide hairs. Only a few show up papillae or faint central masses.

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Each one of the 51 to 54 blades, arranged in a double row, has a papilla between two small sharp tips.

Cyligramma latona Cram. (Fig. 12)

The galea has elements resembling those in Sphingomorpha chlorea in Fig. 10: hairs are absent, the 92 to 107 blades (5 galeae examined) are similar and there are two rows of enlarged plates in the apical region.

In C. latona the plates of one row are enlarged much more than those of the other row and their sharp tips are directed distally. The plates persist right up to and project beyond the tip of the galea. These enlarged plates probably only have a slight rasping action during feeding due to their weakness.

The tip of the galea is round, lightly sclerotized and laterally demarcated by cuticular folds. The teeth and hooks, but especially the latter, are much enlarged towards the galeal tip compared to those further proximad. Shortened ribs persist up to the galeal tip. The channel pegs number 27 to 37 and a labial brush is absent.

Ulotrichopus tinctipennis Hmpsn.

The one galea examined resembled somewhat that of Cyligramma latona, Fig. 12. The 58 galeal blades are similar to those of the latter species, but they have six minute pointed tips. Galeal hairs are absent.

In the middle of the intermediate region a second row of small pointed plates is visible, while in the apical region the plates of both rows are considerably enlarged and their

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pointed tips are directed distad. The most distal ones project a little beyond the blunt and slightly sclerotized tip of the galea.

In the one galea 37 channel pegs were counted.

As already observed in IV. ORCHARD STUDIES, non-piercing moths may imbibe sweet juices on the dorsal side of the proboscis in the apical region. The proboscis of all the non-piercing moths that were examined (Achaea spp., Anua spp., Cyligramma latona, Grammodes stolida, Parallelia algira, Sphingomorpha chlorea and Ulotrichopus tinctipennis), had two rows of slightly enlarged to greatly enlarged plates in their apical regions. These enlarged plates do not close the food channel dorsally, as is the case in the intermediate and basal regions of the proboscis, so that fluids like fruit juices can be ingested or saliva can be discharged dorsally in the apical region.

Except for Serrodes, the piercing moths examined in this study (Calpe spp., Othreis materna, Pericyma spp. and Serrodes partita) have a continuous band or ribbon of plates. The two rows of plates in Serrodes presumably constitute a less firm dorsal linkage or closure of the food channel, allowing fluids to be imbibed when the proboscis is held in a position as shown in Fig. 1e.

The galeal brush does not appear to be a structure that is of great importance during feeding, nor of any importance during piercing. Presumably its functions are to superficially rasp fruit flesh and, if it is dense as for example in Serrodes partita (Fig. 6), to act as a filter of imbibed liquids.

Othreis materna (Fig. 7) possesses a proboscis which

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appears to be the most specialized of the piercing species that were examined. The thick, obliquely-directed, broken ribs with apodemes suggest that the proboscis is very sturdy, but at the same time still able to perform the movements described for the piercing moths during the act of piercing. The presence on the galeal tip of heavily sclerotized ridges, an immovable barb and sclerotized projections near the galeal tip which, as already stated earlier on, probably represent the fused barbs and their distal elevations, are all further evidence of this specialization to pierce hard fruit.

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VII. DISCUSSION

A. Differences between piercing and non-piercing moths as observed in orchards and on caged moths

From the experiments with caged moths it is evident that fruit-feeding noctuids used in these tests can be separated into two distinct groups: the piercing moths that can pierce intact hard peaches and the non-piercing moths that cannot penetrate with their probosces the intact skin of even very soft and ripe peaches, plums, pears and grapes. The latter group, namely Achaea spp., Anua tirhaca and Sphingomorpha chlorea, include the same species found to feed on damaged and rotten fruit in orchards (Table 1, p. 23).

From the same table it can be noticed that those moth species in the category "Sound fruit" are the ones found in the cage experiments to be able to pierce intact peaches, namely Calpe spp., Pericyma spp. and Serrodes partita. If their numbers in the category "Sound fruit" are compared to those in the categories "Damaged fruit" and "Rotten fruit", it can be deduced that those species which are able to pierce intact fruit, actually prefer to feed on fresh undamaged fruit in nature. The cage tests showed that not even very hard and green peaches were a barrier to prevent these moths from feeding.

Of those moths unable to pierce the intact skin of fruit, five species were tested in the cage experiments for their ability to pierce or penetrate with their probosces the fruit flesh of pared fruit. The three Achaea spp. and Anua tirhaca that were tested, were able to penetrate with their probosces into the flesh of ripe peaches and plums. The transition stage for these species, where penetration of pared fruit was observed to take place and then observed to be im-

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possible, is between 3,3-4,0 lbs (Achaea) for Wicksen plums (Table 14), between 3,5-4,5 lbs (Achaea) and 3,5-6,0 lbs (Anua) for Keimoes peaches (Tables 14 and 17 respectively) and between 5,5-8,5 lbs and 5,4-8,8 lbs (Achaea) for Transvaal Yellow peaches (Tables 15 and 16 respectively). (The numbers denote values obtained with a USDA fruit pressure tester.)

The penetration of fruit flesh by Achaea spp. and Anua tirhaca is not considered here to be a piercing action strictly in the sense of the action of true piercing moths observed in this study (Calpe spp., Othreis materna, Pericyma spp. and Serrodes partita), because Achaea and Anua do not display a deliberate boring action on one spot with oscillation of the head and the vibration of the proboscis. The action with their proboscis on the pared surface of the fruit is more of a jabbing nature until entrance into the fruit flesh has been gained, after which the already described oscillation of the head and the sliding of the galeae may be observed.

Cage tests with Sphingomorpha chlorea revealed the inability of this species to penetrate with its proboscis the fruit flesh of soft, very ripe peaches and plums which gave the lowest values recordable on the USDA fruit pressure tester namely 3,0 lbs and less. For Achaea spp., Anua tirhaca and S. chlorea the barriers that prevent them from feeding on fruit are firstly, the intact skin of the fruit and secondly, the hardness of exposed fruit flesh.

Fruit-feeding noctuids that were also observed to feed on the nectar of flowers and of extrafloral nectaries, on dewdrops and on juices from an injured tree trunk, never included piercing species. Except for one observation with Serrodes partita, piercing species were never observed to feed on dried fruit juices reliquified with their saliva, an observation often made on non-piercing species.

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It was observed during the orchard studies that the fruit-feeding butterfly Charaxes saturnus displayed no sliding of its galeae during feeding, while a group of noctuid fruit-feeding moths which include Parallelia, Grammodes and Sphingomorpha show a slight sliding of their galeae. In the piercing species and also in Achaea and Anua there is a strong sliding movement.

It has already been shown what importance this sliding has in the act of piercing and the laceration of fruit pulp. The lepidopterons in which this sliding is weakly developed are therefore less well adapted to fruit feeding, even more so where no galeal sliding takes place. Sphingomorpha chlorea, which shows the least sliding of the galeae of those noctuids that were examined, exhibits quick, strong probing movements during feeding. These movements would enable this well-known fruit feeder to rasp the fruit pulp with its galeal blades to liberate juice.

B. Differences between the mouthparts of piercing and non-piercing moths

When examining the proboscis of fruit-feeding noctuids, there are three obvious differences between piercing species and non-piercing species:

1. Non-piercers have a gradually tapering proboscis, whereas piercers have a non-tapering proboscis with a wedge-shaped tip (dorsal or ventral view).

2. Non-piercers have slightly pointed to blunt galeal apices with sclerotization absent or limited to the extreme tip against the very heavily sclerotized and sharply pointed galeal apices of the piercers.

3. Piercers have galeal barbs, which are absent in

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non-piercers.

Each one of these differences will now be discussed:

1. Bänziger (1970) made schematic drawings of the outlines of proboscis (dorsal or ventral view) of six noctuid moths (3 piercing species, 1 non-piercing fruit-sucking species and 1 nectar-sucking species). In the latter two species the proboscis gradually tapers from the base towards the tip, whereas in the piercing species "only an almost imperceptable tapering of the proboscis occurs from the base to approximately the middle of the length, after which the proboscis thickens again almost imperceptibly towards about 1/12 of its length from the tip, where a sudden nearly triangular pointing is noticed".

In the present study the Calpe spp., Pericyma spp., Serrodes partita and Othreis materna display the same outlines of their proboscis as described by Bänziger for the three piercing species. All the other moths possess probosces which gradually taper towards the tip.

2. Of all the non-piercing species examined, the galeal apices of Achaea and Anua (Figs. 8, 9) are the most sharp and most sclerotized. About Achaea catella Bosch (1969) says that it "can cause secondary damage to soft fruit, particularly grapes. Once the skin has been broken, this moth can push its proboscis into the fruit tissue; the abrasive action of the proboscis as well as the removal of juice causes destruction and collapse of the tissues. Damage caused by this species is very similar to that caused by the true fruit piercing moths." Her findings tally with observations made in this study on caged moths and in orchards.

Achaea spp. and Anua tirhaca were able to penetrate with

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their probosces the fruit flesh of ripe pared fruit, while Sphingomorpha chlorea was unable to gain entrance with its proboscis into very soft fruit flesh. This is not altogether surprising when the soft flabellum-tipped apex of the proboscis of Sphingomorpha is considered.

Bosch (1969) commented on Cyligramma latona as follows: "These moths can only suck juice oozing from damaged fruit." Her conclusion corresponds with findings made in this study, namely that this species prefers feeding on soft rotting fruit (see Table 1) and that it has a blunt proboscis (Fig. 12) with elements resembling those of Sphingomorpha chlorea.

3. Bänziger (1970) found that the fruit-piercing Scolyopteryx libatrix did not possess distinct galeal barbs, but that "crenatures" in their place fulfilled the same function of tearing the skin of fruits. Breitenbach (1882) classified these "crenatures" as barbs, although he noted that they were poorly developed. It is not known whether Bänziger's "crenatures" of Scolyopteryx resemble in any way or are similar to the ridges, projections or the immovable barb of Othreis materna.

The galeal apices of Achaea and Anua (Figs. 8, 9) have the most distal blades short and less flattened, almost similar to the squat tubercles. It is not unlikely that during the evolution of the galeal barbs a stage was reached where the barbs were represented by structures similar to the tubercles of Achaea and Anua.

The ability of Achaea and Anua to penetrate exposed fruit flesh which the well-known fruit feeder Sphingomorpha chlorea cannot and the fact that they possess relatively sharp, sclerotized galeal apices with stout sap borers, makes them the most advanced fruit feeders of the non-piercers en-

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countered in this study.

It is theoretically possible that in future studies fruit-feeding moths will be discovered that are able to pierce the intact skin of some soft-skinned fruit but not of other fruit with tougher skins. Bänziger (1969) regards Parallelia (= Dysgonia) algira as a piercer after field observations in which he found that this moth usually inserted its proboscis between the individual small berries of the compound fruit of the blackberry (Rubus sp.) and that it then (probably) pierced the skin of the berries. He found too that this species only fed on figs, peaches and grapes of which the skin was damaged.

Two functional differences between piercers and non-pierces that may still be found in future research to be of importance, are mentioned here:

4. If the two galeae of a noctuid proboscis are pulled apart (laterally) starting from the basal region, the two halves of the proboscis separate fairly easily along its entire length, except in the piercing species where the separation is resisted in the apical region by the ventral linkage.

The significance of this resistance can only be understood if the importance of the sliding of the galeae in the act of piercing and feeding is remembered, especially during the spindle-like vibrating movements. If the linkage should have been weak or absent, a piercing moth would not have been able to adopt a posture with its proboscis during piercing as it is shown, for example, in Fig. 1h.

5. By moving a smooth object along a galea from the base of the latter towards its apex and thus artificially increasing the inside pressure, it was demonstrated in this study that the galeal blades of piercing species became erect.

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With increasing pressure the blades were forced to point proximad. In the piercing species of this study, an erection of the galeal barbs was also noticed during increased pressure.

When the same artificial pressure was applied to the galeae of Anua spp., Achaea spp. and Cyligramma latona, their galeal blades were noticed to lie backwards (proximad) only slightly from their usual upright position, whereas in Sphingomorpha chlorea they did not move and stayed upright.

Bänziger (1970) demonstrated experimentally that the galeal blades in live Calpe thalictri can be actively erected by blood pressure, the latter which also confers a certain rigidity on the proboscis as a whole. The erected blades aid in the penetration of fruit pulp by the proboscis through their braking action, which takes place alternatively on the two galeae when the blades point proximad and distad. Whether the blades of other fruit-feeding moths serve the same function, is not known. It may be possible that this characteristic is restricted to the piercing species.

The following four differences between piercing and non-piercing noctuids are given by Bänziger (1970): i) The ratio of the average thickness to the length of the proboscis which is at least three times higher in piercers. ii) The tapering proboscis of non-piercers against the practically non-tapering proboscis with a sharp triangular tip. iii) The armature in non-piercers consists of galeal hairs and/or simple bristles or setae, none of which are fixed. iv) In piercers there are four stipital muscles, two of which accomplish the sliding of the galeae, while non-piercers have three stipital muscles maximally.

Points ii) and iii) have already been discussed. On points i) and iv) the following comments are made:

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Bänziger (1970) found the ratio of the average thickness to the length of the proboscis "in the three piercing moths Calpe thalictri Bkh., Calpe eustrigata Hmps. and Scolyopteryx libatrix L. at least three times higher than in the nectar-sucking Autographa gamma L. and the fruit-sucking Lygephila craccae F. This means that the proboscis of the former is about 10 times stronger than that of the latter." The ratio used by Bänziger to differentiate between piercers and non-piercers was found not to be a useful criterion to separate the moths of which the proboscès were examined in the present study.

The musculature and its functions was not investigated in the present study. In the light, however, of the strong sliding of the galeae observed also in some non-piercers, the number and role of the stipital muscles would have to be investigated in these moths. The following example will serve to illustrate that a variation in the number of specific muscles of the mouthparts of piercing species is possible: Swart (1969) found the secondary oblique galeal muscles in Serrodes restricted to the "knee-bend" area of the intermediate region of the proboscis, while Bänziger (1970) found these muscles in Calpe throughout the whole length of the proboscis. Srivastava & Bogawat (1969) found the same muscles present only in the apical region of the proboscis of Othreis.

With regard to differences between piercing and non-piercing moths, Swart (1969) "found that the only anatomical differences between these two groups are that the galeal apices of species with 'modified' proboscides bear galeal spines (barbs in the present study) and galeal blades and have strong, sharply pointed tips, whereas the galeal apices of species with 'unmodified' proboscides lack galeal spines, but bear galeal blades and have weaker, more rounded tips."

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C. General

Some theoretical ideas are now presented as to how the fruit-piercing method of feeding has possibly evolved in nature. The mandibulate Micropterygidae and Lepidoptera with atrophied mouthparts are excluded from this discussion.

The proboscis allowed lepidopterons to imbibe a diversity of readily available fluids e.g. moist dung by Charaxes spp. (Nymphalidae), muddy water by some Lycaenidae, lachrymal fluids of ungulates by Arcyophora spp. (Noctuidae) and floral nectar by members of a number of lepidopterous families. No special structures were necessary on the proboscis to obtain these fluids.

To procure fluids less readily available than those mentioned, e.g. from fruit or nectariferous tissue, a variety of sap borers developed on the proboscis of lepidopterons of different families. These sap borers lacerated plant cells to release their juice which was then sucked up. This laceration was brought about by the twitching movement in the apical region of the proboscis or by the probing of the whole proboscis, as in Sphingomorpha chlorea. The sap borers were pressed into the plant cells or rasped across them through these movements.

To release more juice from the flesh of soft fruit than just by twitching or probing with the proboscis, the sliding of the galeae was the next step, with more sap borers, especially galeal blades, developing on the distal part of the proboscis, for example as in Cyligramma latona.

Because no more than just soft fruit pulp could be utilized with the soft-tipped galeae, a gradual sclerotization of galeal apices took place while sap borers in the same apical region became more squat and tubercle-like, enabling the moths to penetrate firmer fruit flesh, scraping and tearing the

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latter with the stouter sap borers (e.g. Achaea spp.).

Penetration of the skin of intact fruit was the next obstacle to be overcome: the galeal apex had gradually become sclerotized, but it was still too blunt to pierce the skin of fruit. Rigid, heavily sclerotized galeal apices with sharp tips alternatively pressed onto the same mark on the fruit skin by way of a very quick sliding of the galeae, eventually overcame the last obstacle.

To be able to further widen the hole made by the sharp tips of the galeae in the tough skin of some fruits like pomegranate or citrus, the tubercle-like sap borers became specialized structures, viz. proximally directed barbs, which could tear the skin and also hard fruit flesh. Although strongly sclerotized, these barbs remained moveable and able to be erected by blood pressure, thus standing erect and partly aiding in penetration because of a braking action, as well as accomplishing their tearing action with the backward stroke of the galea (e.g. Calpe, Pericyma, Serrodes). In some fruit-piercers strongly-sclerotized ridges and projections on the proboscis tip then performed the tearing action of the specialized barbs (e.g. Othreis, ?Scolyopteryx).

The rasping and piercing function of the galeal blades became less important in such piercing moths where barbs on the galeal apex fulfiled their tearing action very well. The function of the blades changed instead to aid the proboscis in the penetration into or withdrawal from fruit flesh. This was brought about by the proximally orientated erection of the blades through increased blood pressure, as opposed to the distally directed position with normal blood pressure. The blades then assumed a braking function (e.g. Calpe).

The availability of foods rich in sugars is considered by the writer as one of the factors which make long-distance

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migration of Lepidoptera possible. The summer-migrating pierid Belenois aurota Fabr. in South Africa continually feeds on floral nectar while on the move. The honey-feeding sphingid Acherontia atropos (L.) has been shown to be migratory in Europe (Harz, 1967). Migratory Achaea lienardi in Africa and Serrodes partita in the South-Western Cape are well-known fruit-feeding noctuids.

Bänziger (1968) discovered in Malaya that Calpe eustrigata is skin-piercing blood-sucking. Caged moths of this species were offered a variety of fruit, but only some individuals fed on peaches. Blood-feeding would make fruit-feeding moths independent from seasonally available fruit. The fact that C. eustrigata was found to feed on peaches, although under unnatural conditions, indicates that blood-feeding was most probably preceded by a fruit-feeding way of life.

Taylor (1965) kept adults of Achaea lienardi alive in cages for some 170 days. These moths bashed themselves about very considerably in the cages. According to Taylor free-flying moths might survive even longer if they escape predation.

For fruit-feeding moths to remain alive for 170 days or longer would necessitate frequent feeding with intervals of not more than three days. (Having fed once, most caged fruit-feeding noctuids in the present study died after three days if they had been left without food.) This necessity to feed frequently could have been one of the factors which led, firstly, to the development of piercing mouthparts which enabled such moths to feed on almost any kind of intact fruit even when the latter was still green and hard, thus prolonging the "food season" and, secondly, to even further specialization: that of blood-feeding, with a resultant "round-the-year season."

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Up to about 1965 the designations "fruit-piercing moths" and "fruit-sucking moths" were used indiscriminately to denote fruit-feeding noctuids, although Jack as far back as 1922 had already differentiated between piercers and non-piercers. He stated that fruit-piercing moths had a specially modified proboscis with "a sharp, horny tip, well adapted for boring purposes", whereas fruit-sucking moths had an unmodified proboscis.

Bot (1967) suggested that the name "fruit-sucking moths" be used for those moths which are responsible for secondary fruit damage and "fruit-piercing moths" for those that cause primary fruit damage. Swart (1969) did not approve of this terminology for two reasons. Firstly, moths did not suck the fruit, but only the fruit juice and secondly, personally communicated information to him suggested that certain species which he found to have unmodified proboscis, were capable of causing primary damage. Swart favoured the term "fruit-piercing moths" to include all fruit-feeding moths and to divide this latter moth complex into species with "modified" and with "unmodified" proboscis.

When Bänziger (1970) compared the proboscis of noctuids, he distinguished the following groups: skin-piercing blood-sucking, fruit-piercing, non-piercing fruit-sucking and nectar-sucking.

In Rhodesia Bosch (1971a) classified fruit-feeding noctuids into fruit-piercing moths "that have a short sharp proboscis capable of puncturing the toughest fruit skin" and fruit-sucking moths that "have a long slender proboscis and can only suck juice once the skin of the fruit has been broken".

Myburgh et al (1973) used the terms "fruit-piercing

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moths" which are "primary feeders" and which cause "primary damage" as opposed to "fruit-sucking moths" which are "secondary feeders", causing "secondary damage".

The present study confirmed what Jack (1922) had already stated, namely that fruit-feeding noctuids can be separated into two distinct groups: piercers that have no difficulty penetrating intact fruit with their probosces and non-piercers which can only feed on exposed fruit flesh. Although considering the abovementioned first objection of Swart, the present author is of the opinion that the terms "fruit-piercing moths" and "fruit-sucking moths" should be retained because they have become understood and accepted names to fruit growers and entomologists.

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VIII. SUMMARY

A description is given of how fruit-feeding noctuids pierce fruit and feed on it. The functions and importance of the following feeding movements are discussed: probing with the proboscis, oscillation of the head, to and fro sliding of the galeae and the vibration of the proboscis. Two proboscis cleaning processes, using saliva and a labial brush, are described.

Moths feeding on fruit in orchards were recorded as either feeding on "rotten fruit", "damaged fruit" or on "sound fruit". Later experiments with caged moths and morphological studies of their proboscis, showed that the moths recorded under the category "sound fruit" are the so-called piercers while those in the other two categories are the non-piercers. Piercers actually preferred to feed on undamaged fruit.

Hourly counts of fruit-feeding noctuids throughout four nights during two seasons revealed that greatest moth activity occurred during the first three hours after dark, followed by a small decrease in numbers around midnight. The numbers increased again at about 01h00 and this number was maintained until 04h00.

To determine whether fruit-feeding noctuids return to the same source of food on subsequent nights, moths were caught on the only peach tree that still bore fruit in an orchard in February. On two evenings the following numbers of moths were caught, marked and released: 4 Achaea catella, 84 A. finita, 65 A. sordida and 13 Sphingomorpha chlorea. The highest percentage return (7,6%) occurred one day after marking. The longest time lapse between marking and subsequent recording was four days (a single specimen).

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Tests with caged fruit-feeding moths revealed that there was a clear distinction between moths being able to pierce the skin of fruit (piercers) as opposed to those that were unable to pierce the skin of even soft ripe fruit (non-piercers). For non-piercers the barriers that prevent them from feeding on fruit are firstly, the intact skin of the fruit and secondly, the hardness of exposed fruit flesh.

A general description of the proboscis of fruit-feeding noctuids is given, followed by a description of the proboscis of individual species. The apical regions of the galeae of nine fruit-feeding moths are figured, namely Achaea finita, Anua dianaris, Calpe provocans, Cyligramma latona, Othreis materna, Parallelia algira, Pericyma atrifusca, Serrodes partita and Sphingomorpha chlorea.

Three morphological differences between the probosces of piercing and non-piercing noctuids exist: 1. the presence of galeal barbs in piercers; 2. the non-tapering proboscis with a wedge-shaped tip of piercers as compared to the gradually tapering proboscis of non-piercers; 3. the very heavily sclerotized and sharply pointed galeal apices of piercers as against the non-piercers' slightly pointed to blunt galeal apices with sclerotization absent or limited to the extreme tip.

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SAMEVATTING

'n Beskrywing word gegee van hoe vrugtestekende motte vrugte steek en daarop voed. Die funksies en belangrikheid van die volgende voedingsbewegings word bespreek: die herhaaldelike insteek van die roltong in die vrugvlees, die slingerbeweging van die kop, die heen-en-weer gly van die galeae en die trilbeweging van die roltong. Twee reinigingsprosesse van die roltong, waarby speeksel en 'n labiale borsel gebruik word, word bespreek.

Motte wat op vrugte in boorde gevoed het, is opgeteken as voedende op "vrot vrugte", "beskadigde vrugte" en op "heel vrugte". Latere eksperimente met motte in hokke en morfologiese studies van hulle roltonge, het getoon dat die motte wat aangeteken is in die kategorie "heel vrugte" die sogenaamde stekende motte is, terwyl dié in die ander twee kategorieë die nie-stekende motte is. In werklikheid het die stekende motte verkies om op onbeskadigde vrugte te voed.

Tellings wat van vrugtevoedende Noctuidae uurliks gemaak is dwarsdeur vier nagte tydens twee seisoene, het getoon dat die meeste motte aktief is tydens die eerste drie uur na donkerte. Dit word gevolg deur 'n klein afname in getal om en by middernag. Hierna neem die getalle weer toe vanaf omtrent 01h00 en word so gehandhaaf tot 04h00.

Om vas te stel of vrugtevoedende Noctuidae na dieselfde voedselbron terugkeer op agtereenvolgende nagte, is motte gevang op 'n enkele perskeboom wat nog vrugte gedra het in 'n boord in Februarie. Tydens twee aande is die volgende aantal motte gevang, gemerk en losgelaat: 4 Achaea catella, 84 A. finita, 65 A. sordida en 13 Sphingomorpha chlorea. Die persentasie van motte wat teruggekeer het, was die hoogste één dag nadat motte gemerk is, naamlik 7,6%. Die langste tyd-

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perk vanaf die dag dat motte gemerk is tot hulle weer gesien is, was vier dae ('n enkele mot).

In proewe met vrugtevoedende motte in hokke is vasgestel dat daar 'n duidelike verskil is tussen motte wat die skil van vrugte kan deursteek (stekende motte) in teenstelling met dié wat nie eens die skil van sagryp vrugte kan deursteek nie (nie-stekende motte). Twee faktore verhinder nie-stekende motte om op vrugte te voed: eerstens die onbeskadigde skil van die vrugte en tweedens die hardheid van die ontblote vrugvlees.

'n Algemene beskrywing word gegee van die roltong van vrugtevoedende Noctuidae, gevolg deur 'n beskrywing van die roltonge van individuele spesies. Die apikale gedeelte van die galeae van nege vrugtevoedende motte word afgebeeld, naamlik Achaea finita, Anua dianaris, Calpe provocans, Cyligramma latona, Othreis materna, Parallelia algira, Pericyma atrifusca, Serrodes partita en Sphingomorpha chlorea.

Drie morfologiese verskille tussen die roltonge van stekende en nie-stekende motte bestaan: 1. die teenwoordigheid van galea-weerhake by stekende motte; 2. 'n roltong by stekende motte wat nie geleidelik spits uitloop na sy punt toe nie en wat 'n wigvormige punt besit in vergelyking met die roltong van nie-stekende motte wat spits uitloop; 3. die sterk gesklerotiseerde skerp punt van die galea van stekende motte teenoor die galea van nie-stekende motte wat net lig of glad nie gesklerotiseer is nie en waarvan die punt stomp of net effens skerp is.

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XI. FIGURES

Abbreviations used in Figures 1-12

bd.	-	band
brb.	-	barb
chl. peg	-	channel peg
c.m.	-	central mass
cy.	-	cylinder
d. bar	-	dorsal bar
enc.	-	endocuticular
exc.	-	exocuticular
f. chl.	-	food channel
flb.	-	flabellum
frt.	-	fruit
gl. bld.	-	galeal blade
gl. br.	-	galeal brush
gl. brb.	-	galeal barb
gl. hr.	-	galeal hair
gl. tb.	-	galeal tubercle
hk.	-	hook
k.b.	-	knee bend
lab. br.	-	labial brush
pap.	-	papilla
plt.	-	plate
sens. bas.	-	sensillum basiconicum
sens. chaet.	-	sensillum chaeticum
sens. pit	-	sensory pit
spk.	-	spikelets
th.	-	tooth
tr.	-	trachea

1a - Position of the proboscis of Sphingomorpha chlorea sucking a rotten fruit with the dorsal side of the apical region of the proboscis.

1b,c - Position in which S. chlorea holds its proboscis when cleaning the latter with its saliva.

1d - Proboscis of S. chlorea during feeding, showing the knee bend (k.b.) and the palpating movement of the proboscis tip on the surface of the fruit (frt.).

1e - Posture of the proboscis of Serrodes partita while

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imbibing reliquified anal fluid past the plates of the dorsal linkage in the apical region of the proboscis.

1f - A frontal view of S. partita indicating the spindle-like vibrations of the proboscis when piercing is commenced. The arrows indicate the oscillating movement of the head that takes place simultaneously.

1g,h - Lateral views of Calpe provocans showing two postures and vibrating movements of the proboscis at the on-set of piercing.

1i,j - Two positions of the proboscis in Pericyma scandulata when piercing is started: curved and straight down.

1k - Frontal view indicating vibrating movements of the proboscis as they appear to the naked eye during piercing in Pericyma atrifusca. The arrows indicate the simultaneous oscillation of the head.

2 - Mesal view of the labial palpus of Calpe triobliqua showing the labial brush (lab. br.) and a sensory pit (sens. pit) which opens laterally. The dense covering of scales has been removed.

3 - Generalized representation of a transverse section through the apical region of the proboscis of fruit-piercing moths. Nerves and muscles have been omitted.

4-12 - Lateral views of the apical regions of the galeae of nine fruit-feeding moths.

13 - Moths intended for laboratory study are caught at night with the aid of a head lamp, glass beaker and a piece of carton.

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14 - Moths belonging to the genus Achaea feeding on peaches at night.

15 - A peach which was used in experiments with caged moths is shown here with the paraffin wax covering, which restricted the feeding of the moths to a small uncovered area.

16 - A peach that was pared after fruit-piercing moths had fed on it to show the spongy, dry areas from which the fruit juice has been sucked up.

17 - A peach cut open to show the decay caused by micro-organisms after the fruit had been attacked by a fruit-piercing moth.

18 - A pared peach to illustrate the eggs (white specks) of drosophilid flies layed inside the fruit after the flies had gained entrance through a hole in the fruit skin made by a fruit-piercing moth.

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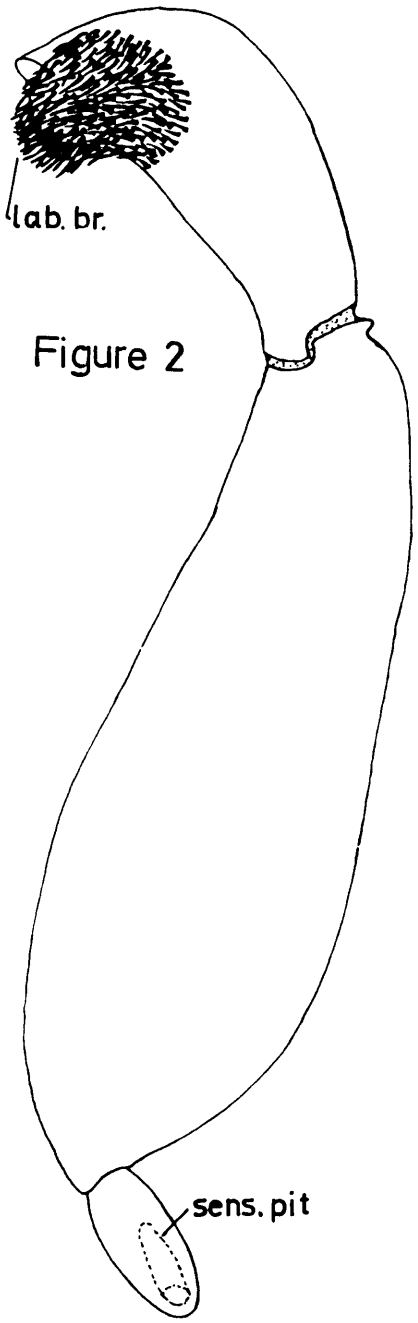
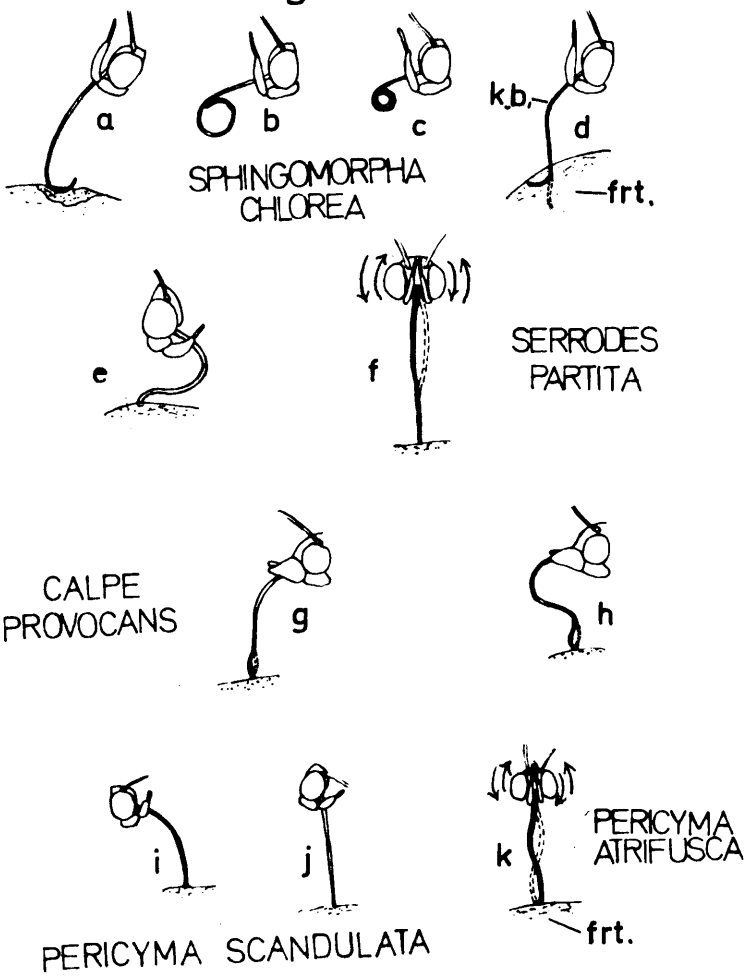


Figure 2

Fig. 2

1,0 mm

Figure 1



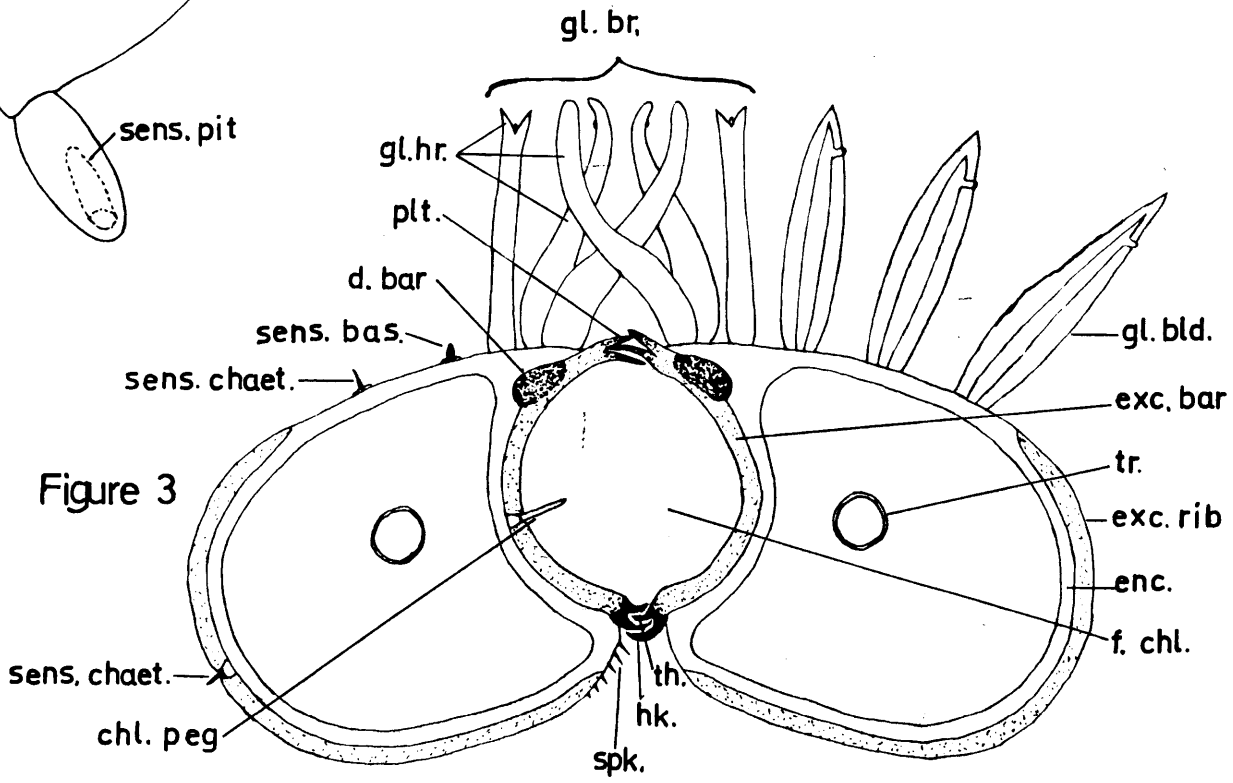


Figure 3

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Figure 1

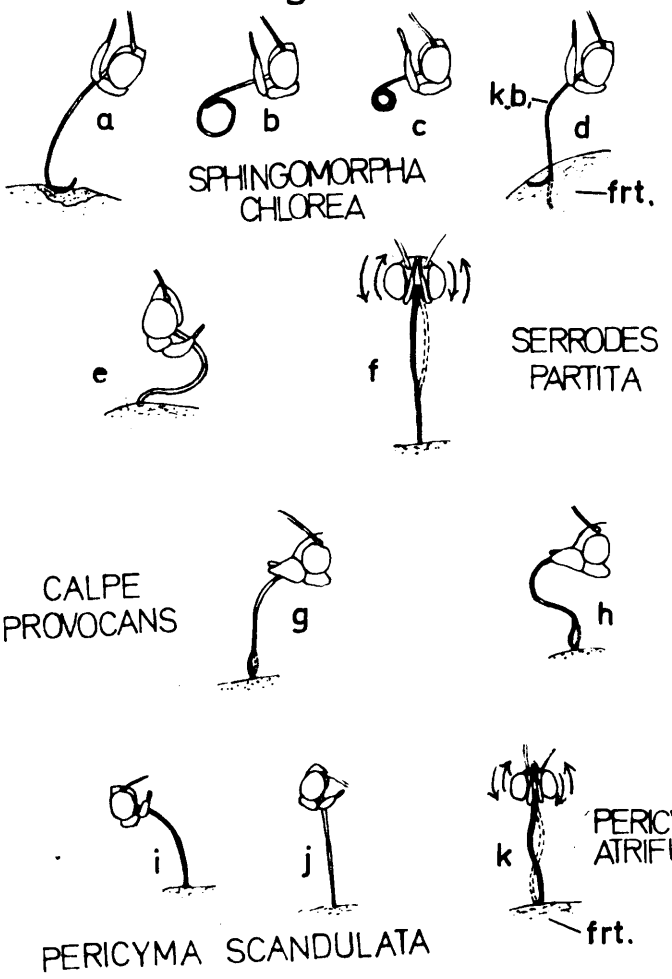


Figure 2

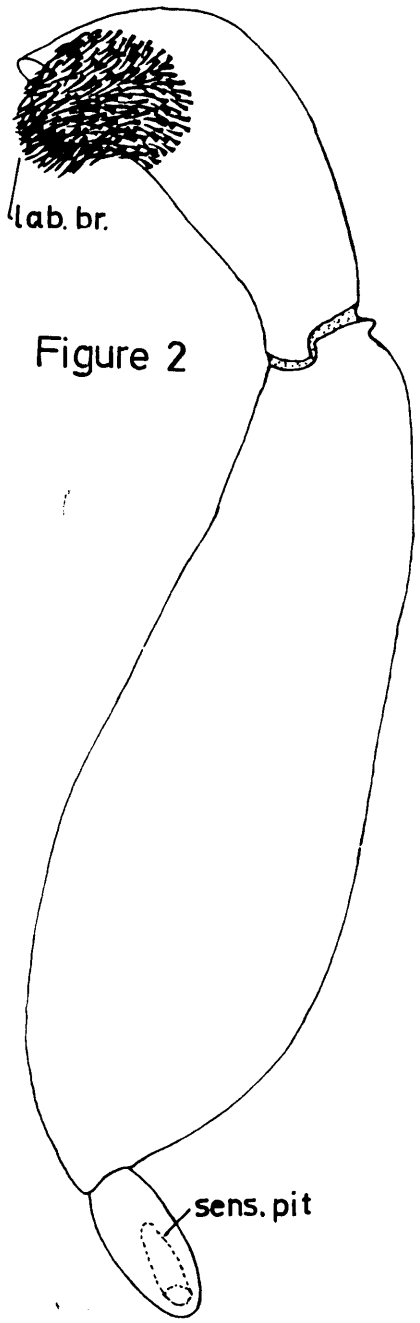
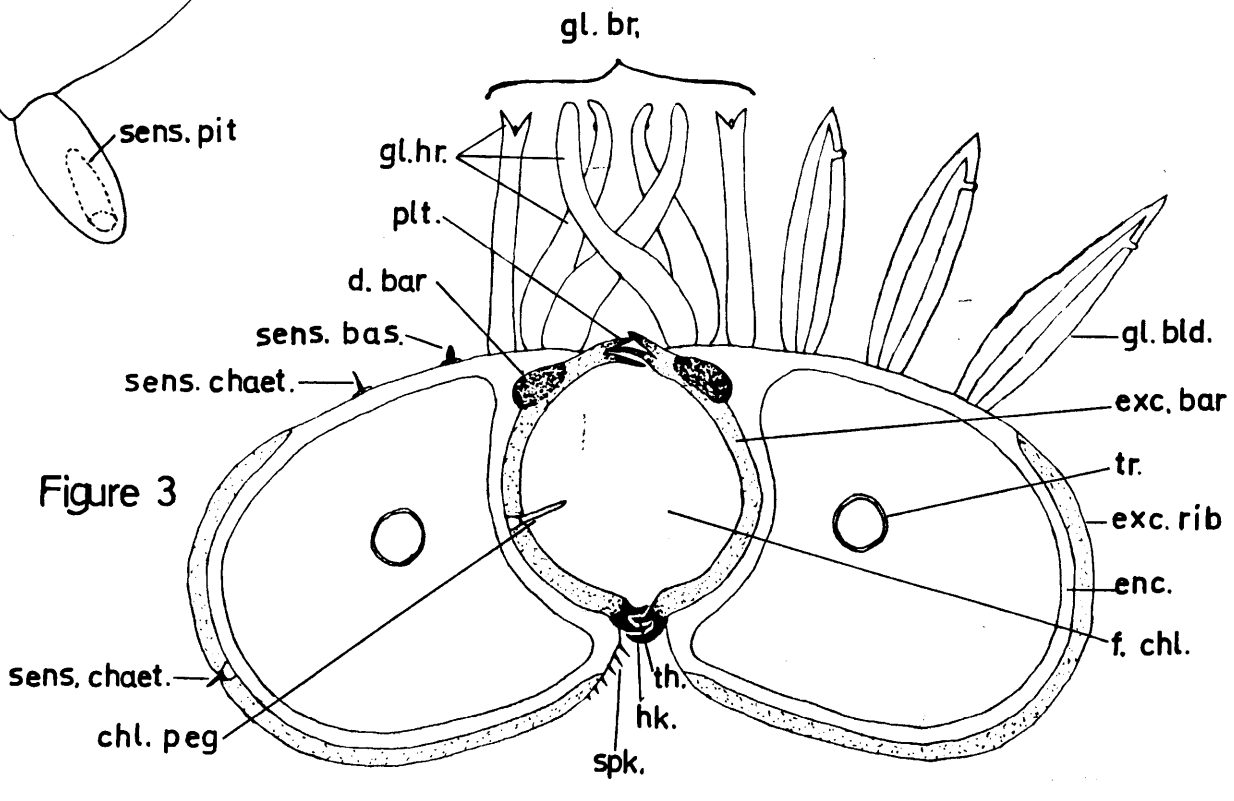


Figure 3



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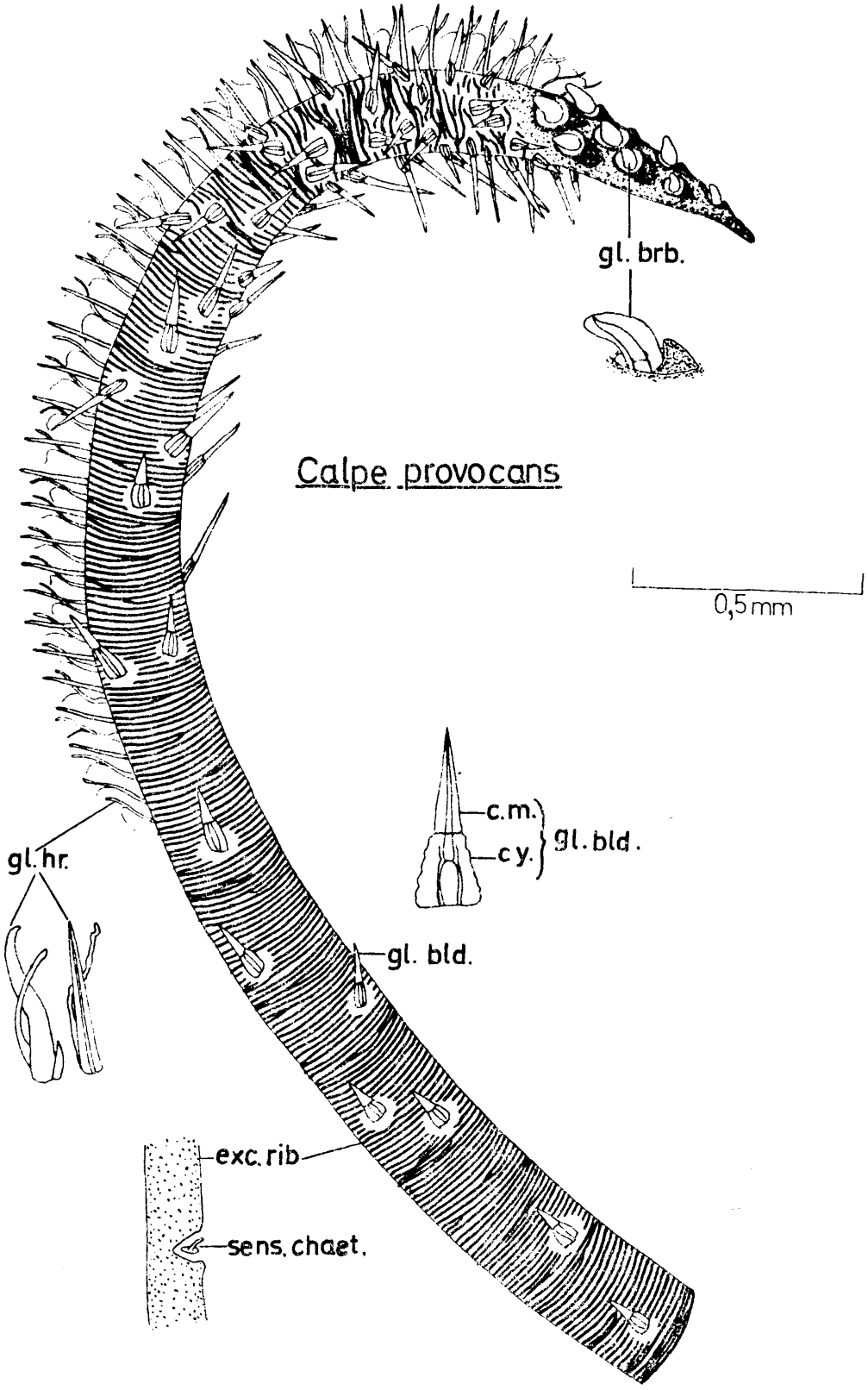

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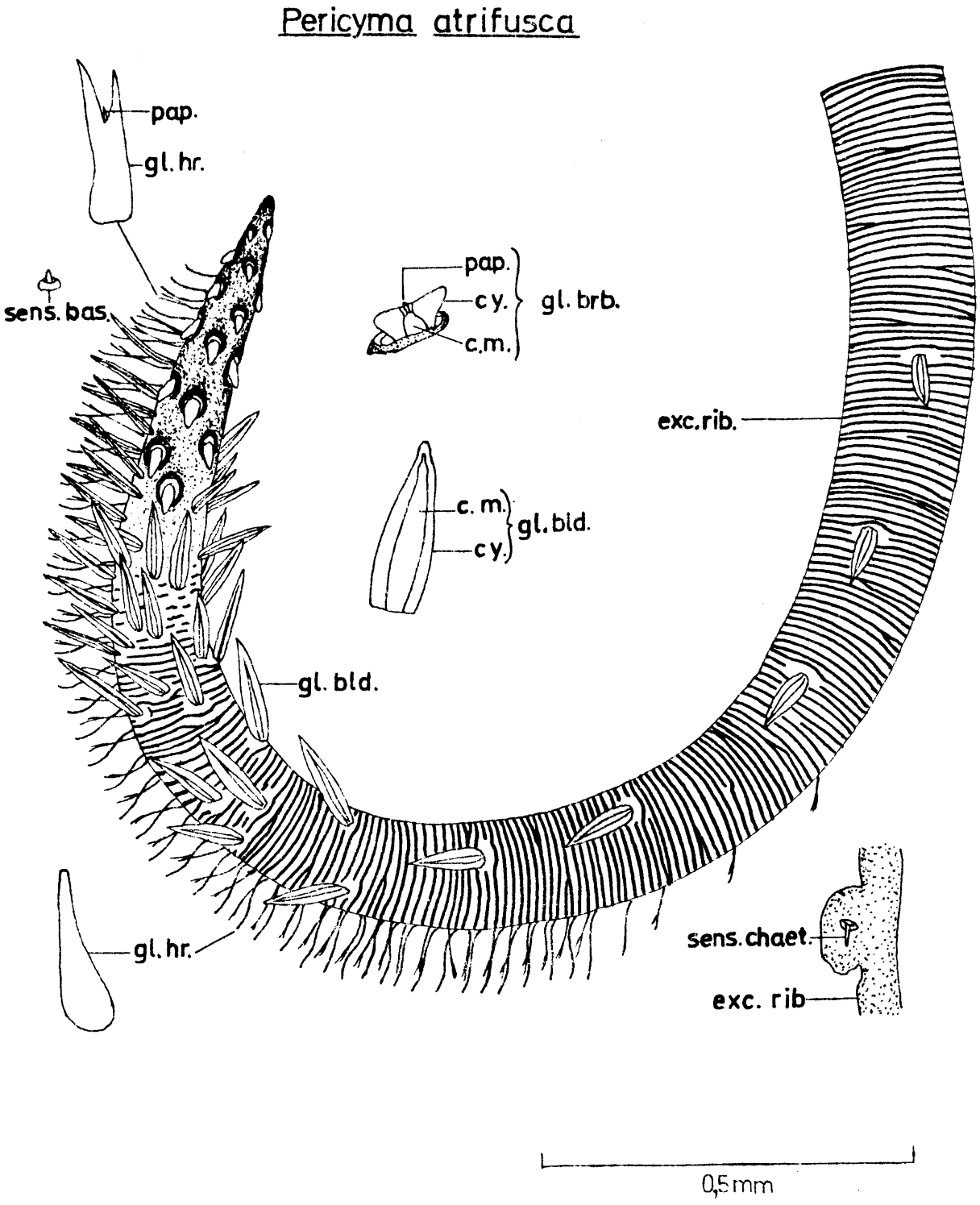

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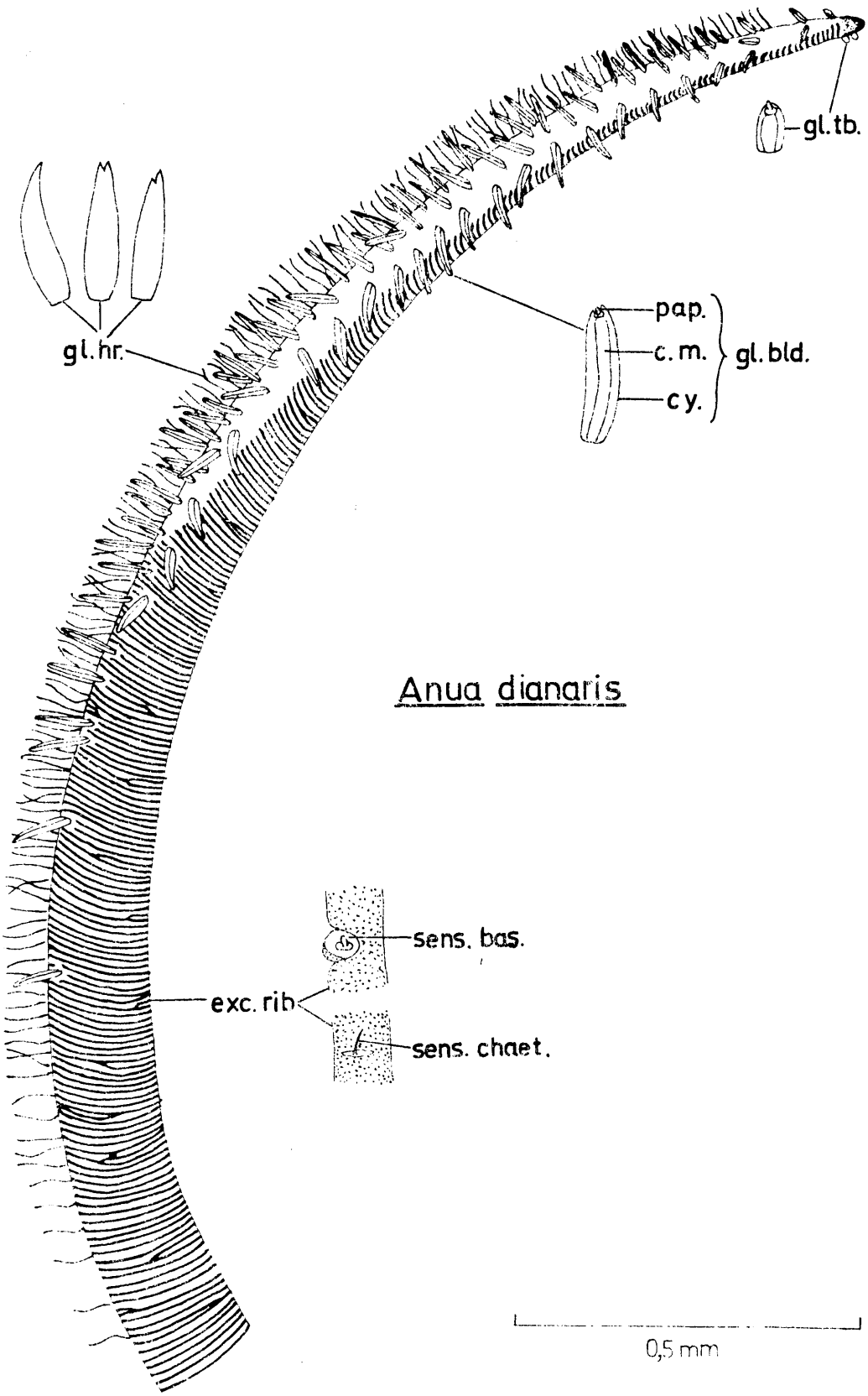

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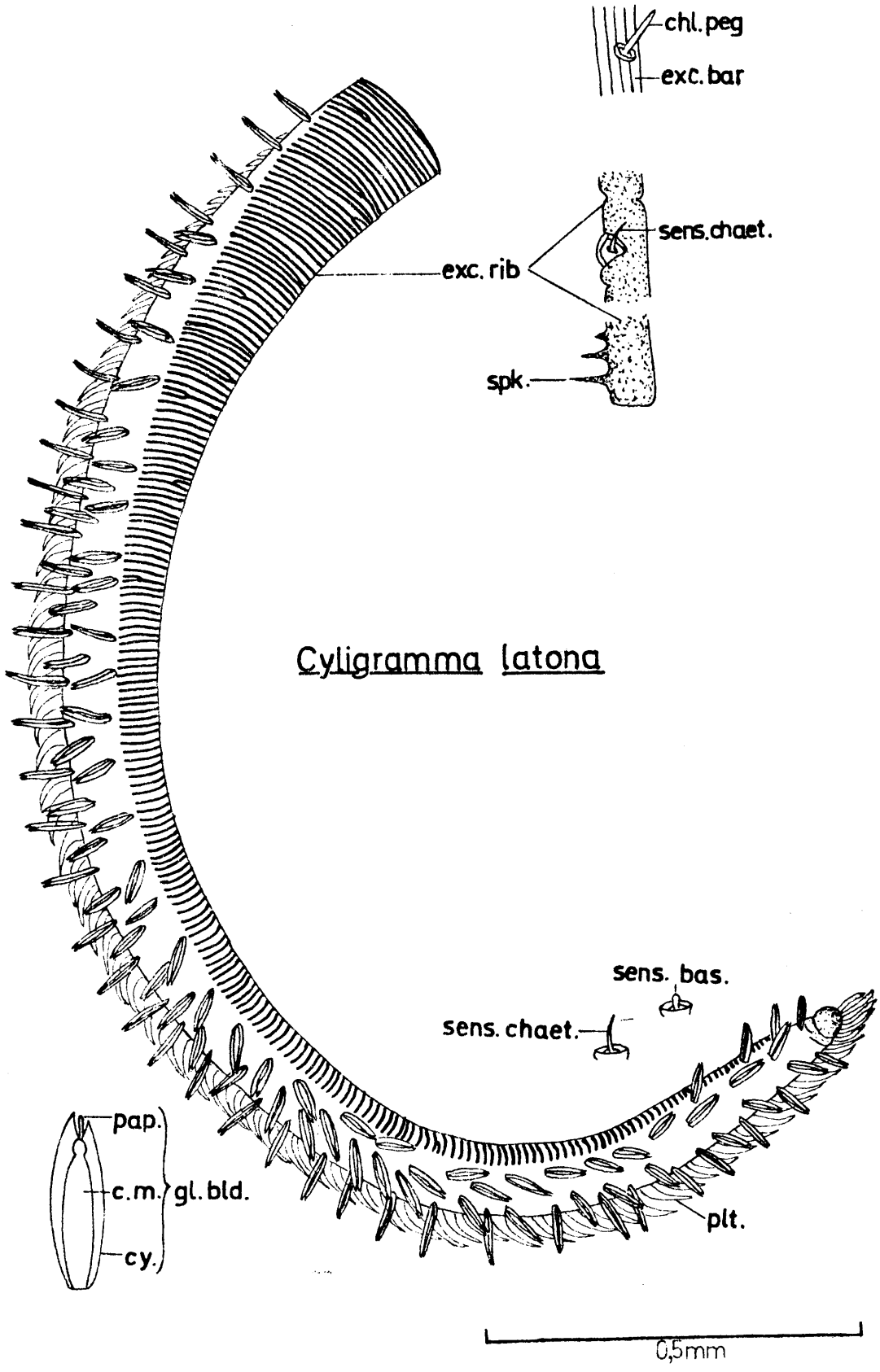

Figure 12

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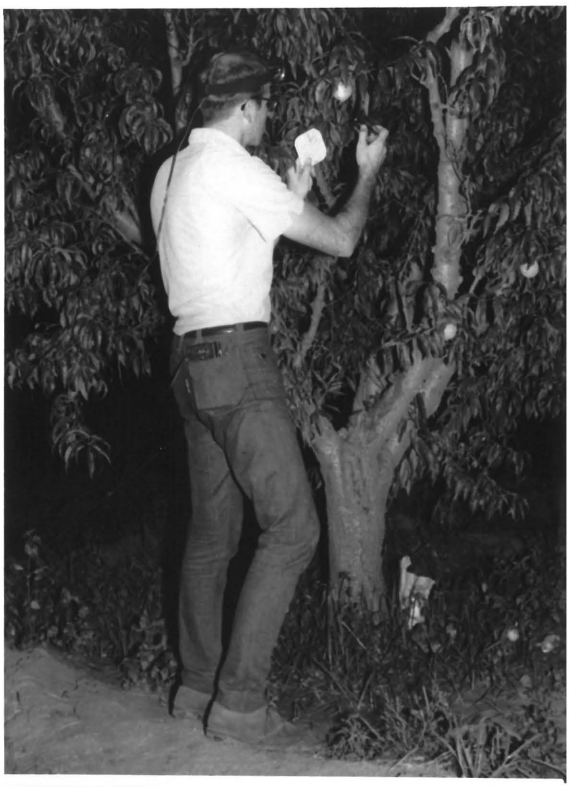

Figure 13

Figure 14

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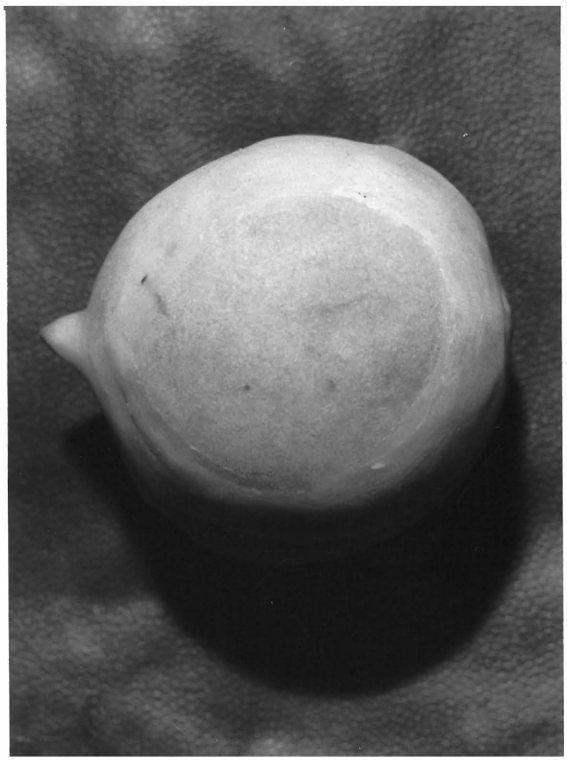

Figure 15

Figure 16

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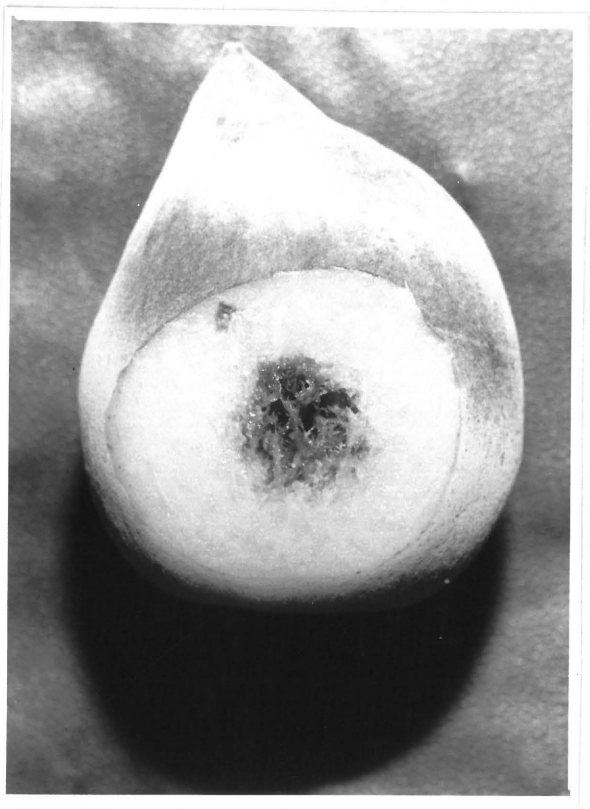

Figure 17

Figure 18

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