THE BIOLOGY OF SOME

PENTATOMOIDEA AND THEIR EGG-PARASITES

By

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A B S T R A C T

This thesis is divided into two sections. The first concerns the bionomics, habitats, reproductive biology of six Pentatomoidea, Heteroptera. The second section deals with eight species of egg parasites (Scelionidae, Hymenoptera) and includes their taxonomy and biology.

The environment in which the six species of Heteroptera, Aelia acuminata (L.), Eurygaster integriceps Put., Neottiglossa pusilla (G.), Palomena prasina (L.), Piezodorus lituratus (F.) and Picromerus bidens (L.) live is described in the first section. Their biology and ecology in southern England and that of E. integriceps in Iran were investigated and compared.

The reproductive morphology of all these species is outlined and the effects of environmental factors, especially of the food and temperature on fecundity and longevity of the adults, was investigated. The effects of these factors on the rate of development of the immature stages was also studied. Particular attention was paid to reproduction in Eurygaster integriceps in view of its economical importance and its status as a serious pest of cereal crops in Iran.

Changes in the sizes of populations of A. acuminata and P. lituratus were recorded at Silwood Park, Berkshire. The problem of

winter diapause, migration and their possible relationship was studied.

In the second section, six newly discovered British species of Scelionidae from the genera Asolcus and Telenomus were investigated. The first key to the identification of these wasps and of the closely related non-British species based on "bio-morphological taxonomy" is constructed. A study was made of the immature stages, adults, and the reproductive morphology of all the species in relation to various hosts and temperatures.

Aggressive behaviour, ability of the parasites to select suitable host eggs, oviposition, copulation, the rate of development and sex ratio of all species, are described. Life histories, resistance to low temperatures, interspecific interference and host specificity of these minute wasps were observed throughout three seasons.

Percentage of parasitism of eggs of several Pentatomoidea by Asolcus and Telenomus species at Silwood and at Yateley, were calculated for 1965 and 1966. New methods of rearing both the shieldbugs and their scelionid egg parasites have been devised.

A preliminary distribution maps of hosts and parasites from the study areas are given for Britain and Iran.

C O N T E N T S

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INTRODUCTION

This is a study of comparative biology, ecology and reproductive morphology of six pentatomoids, Heteroptera, and eight of their scelionid egg parasites including their taxonomy in Britain and Iran.

The hemipterous species include five phytophagous forms Aelia acuminata (L.), Eurygaster integriceps Puton, Neottiglossa pusilla (G.), Palomena prasina (L.), Piezodorus lituratus (F.) and the predacious Picromerus bidens (L.).

Except the well known scutellerid E. integriceps which is a serious pest of wheat and to a lesser extent of barley cultivations in Iran, and in some other parts of its distribution, the other five species belong to the family Pentatomidae and are found in southern England. These species are of much less economic important; the four phytophagous species are pests of cereal and other crops in some parts of the palaearctic region and of Morocco, while the predacious P. bidens is a beneficial insect.

The phytophagous species appear in the field in spring and attack the young green shoots or the buds of their host plants, causing them to die; later during the grain or pod formation the insects turn their attention to the grains or seeds and feed extensively on them, sometimes causing severe damage and destroying crops or the host plants.

The hymenopterous parasites belong to the family Scelionidae and to the genera Asolcus and Telenomus. They are Asolcus davatchii sp.n., A. nixo-martini sp.n., A. silwoodensis sp.n., A. waloffae sp.n., Telenomus sokolovi Mayr and T. truncatus Mayr. These egg parasites

were collected in southern England and all are first records for Britain; four Asolcus spp. are new and have not been described before.

Most of the other known egg parasites of Pentatomoidea such as A. grandis Thomson and A. semistriatus NS (Delucchi) were also collected and bred on various hosts and studied in order to identify the new and the other species. All these hymenopterous egg parasites belonging to the family Scelionidae are important agents in the biological control of the pest species of Pentatomoidea, particularly in sub-tropical climates.

The present work is divided into two sections; the first section is the study of Pentatomoidea or the hosts, and in the second section, deals with their hymenopterous egg parasites.

Up to now, most basic research on the biology of these Hemiptera and Hymenoptera have been done in the U.S.S.R. and in the countries of the Middle East. For example, a great deal of work has been published on the biology of E. integriceps and its egg parasite A. semistriatus (Fedotov, 1947 - 60; Puchkov, 1961 and 1965; Viktorov, 1960-64; Talhouk, 1961).

Until recently, very little was known about these insects in Iran (Alexandrov, 1947 - 49; Vodjdani, 1954). The heavy reduction of wheat and barley crops caused by the attacks of Eurygaster and Aelia however, persuaded the Iranian Government to conduct a long term programme of research which was organised by the Central Treaty Organisation (CENTO) and the Food and Agriculture Organisation of the United Nations (FAO) to study these pests and the methods of their control

(Banks et al., 1961; Brown, 1962 - 66) Martin et al.(unpublished, 1960-64) Remaudière et al.(unpublished, 1960 - 63).

In Europe, a little quantitative work has been done on several of these insects (see Boselli, 1932; Tischler, 1937 - 39; Mayné and Breny, 1948; Dupuis, 1947 - 52). Comparatively little is known about these Heteroptera and nothing is publisged on their hymenopterous egg parasites in Britain (Butler, 1923; Southwood and Leston, 1959).

At the commencement of the present study however, all the available literature was considered and attention was paid to those aspects which either were not studied previously or needed to be clarified or confirmed. I began this work in Iran, where I had the opportunity to work on a survey project of the "Sunn Pests" with FAO, particularly on its biology and ecology. It was then proposed by the Plant Pest and Diseases Research Institute in Tehran that I should continue this study with the support of FAO at the Imperial College Field Station, University of London.

The present survey consisted of:-

1) The study of seasonal changes and numerical estimations of certain common species of Pentatomoidea in a selected area in or near Silwood Park.

2) Investigations of the ecology and distribution of pentatomoids occurring on leguminaceous plants and their scelionid egg parasites with special reference to:-

i) Feeding habits and behaviour of the insects in their breeding areas.

ii) Location of aestivation and hibernation sites.

iii) Annual cycle and voltinism of host bugs and their egg parasites, and the effect of environmental conditions on them in southern England.

3) A comparative study of the reproductive morphology and fecundity of the heteropterous and hymenopterous species.

4) The effect of food, temperature, copulation and crowding on fecundity and longevity of these insects.

5) Research on the methods of rearing and breeding of Pentatomoidea and their egg parasites, and attempts to find a suitable host for rearing the scelionid parasites continuously throughout the year.

6) Observations on migratory movments, and the diapausing period in relation to the sexual maturation of these insects.

7) The developmental period of immature stages and the overwintering period of hosts and parasites.

The following points were also studied when opportunity occurred:-

8) Evaluation of the naturual parasitism of the eggs of Pentatomoidea by scelionid parasites in southern England.

9) Repetition of experiments on fecundity of E. integriceps feeding on wheat grain or its shoots, carried out by Martin et al. and others, but using the newly designed cages and also effects of barley grain or its shoots as food.

10) Research on the taxonomy of Asolcus and Telenomus egg parasites of Pentatomoidea based on both biological characters (i.e. voltinism, oviposition behaviour, host specificity) and morphological characters, and attempting to construct the first key to the six newly

found scelionids in Britain and to those of closely related species occurring in Germany, Iran, Morocco and Russia.
And finally, to attempt to see "how certain species of Pentatomoidea such as Eurygaster integriceps has become a serious pest in some areas of its distribution as in Iran; and also whether these scelionid egg parasites could be used in the control of the population of these Heteroptera in nature."

It was realised that this was a very ambitious programme, and impossible to do within three years, but I received much co-operation from many colleagues in different countries and in Britain.

Among the pentatomoid fauna in southern England, Aelia was commonly found in open grassland, Piezodorus was very common in the southern areas of the Thames Valley, being widely distributed on gorse (Ulex europaeus L.) and broom (Sarothamnus scoparius (L.) Wimmer).

Palomena was scarce and collected in meadows and in broom, bramble, birch, and particularly on hazel. Neottiglossa was found in habitats similar to those in which Aelia occurred. The predacious Picromerus was widely distributed among crowded shrubs in heathland close to woodland; particularly in habitats where immature stages of lepidopterous and coleopterous insects were found in large numbers. And lastly a regular supply of E. integriceps was obtained from Iran.

Piezodorus lituratus was commonly found feeding on broom in an area called the Gunnes's Hill at Silwood Park. Therefore, this area was selected as suitable for a quantitative study of the seasonal

changes of a relatively self-contained population. Survey was also carried out on a population of A. acuminata which occurred on grasses in an area called the North Gravel at Silwood. Biometrical measurement was also applied to P. lituratus.

Studies of reproductive biology were made on all the species of hosts and parasites. Special attention was paid to E. integriceps and A. acuminata in relation to food and temperature, because of their practical and theoretical consequences as pests of cereals. The problem of winter diapause in adults of the phytophagous species was particularly studied in E. integriceps, since it has been neglected in the past. The diapausing period was also investigated in P. bidens which overwinters in the egg stage.

Observations were carried out on oviposition sites, weight, longevity, host and food plants, the rate of development and migration of these insects in different localities in southern England, particularly at Silwood, Yateley and in the New Forest. The data so obtained provide better understanding of the phenology of the phytophagous hemipterous insects and their distribution as well as their scelionid egg parasites.

The predacious Picromerus bidens and its parasites were also studied, both in the field and in the laboratory. The investigations of the biology of this species of Amyoteinae indicated that P. bidens is entirely a predacious insect and can be culture successfully in the laboratory. The eggs of Picromerus were effectively used in culturing the polyphagous egg parasites of Pentatomoidea; this is very important for the study of these scelionid parasites, but was not known previously.

During the course of these investigations, it became very clear that the taxonomic position of certain species of Asolcus and Telenomus were not in a satisfactory state, and that determination of certain species based only on their morphological characters was not always correct. Thus a series of experiments were made in the field and in the laboratory, and cross-breeding tests between the closely related species collected in southern England, and those from Iran and Morocco were attempted. The results confirmed that the biological features of some species, shoudl also be considered, and their identifications are based on "bio-morphological taxonomy."

Recently, a considerable attention has been paid to the culturing methods of Pentatomoidea and their egg parasites in several countries, and certain methods have been established, but all of them were unsuitable both for hosts, and particularly for the parasites. Thus, a new method had to be evolved. These problems of rearing were solved during this study. Culturing of the scelionid egg parasites on the eggs of Picromerus in new cages, continuously through the year, was successful, and provided an opportunity for some research to be carried out which can be continued in Britain and abroad in future.

With small modifications, the methods used in culturing Pentatomoidea and their scelionid parasites have also been successfully applied in culturing other species of Heteroptera, such as the families Coreidae, Lygaeidae, Pyrrhocoridae, and Hymenoptera from the families Aphelinidae, Mymaridae, and Trichogrammatidae. Therefore, the new methods of culturing these insects are expected to have a wide application. Figures 79 , 80, show the distribution of the Pentatomoidea and their scelionid egg parasites studied in Britain and Iran.

DESCRIPTION OF AREA OF STUDY

1. Area in Silwood Park (Fig. 1)

Silwood Park is an area about 93.15 hectares (230 acres), situated about 25 miles towards the south-west of London, near Ascot in Berkshire, at an altitude of 200 ft. The soil is mostly sandy and lies on beds of Eocene age, namely Bracklesham beds. In places these are covered by river deposited gravel, from the terraces of the Thames (Sherlak, 1947).

Silwood Park lies in that part of England which has the nearest approach to a continental climate, having relatively hot dry summers and cold winters (Richards and Waloff, 1954).

Vegetation:

The greater part of the area is covered by acid grassland of a rather uniform type, but the pH is not very low except around the area of the lake where acid peat has been formed and there no pentatomoids were found. The grassland is dominated by Festuca rubra (L.), Agrostis tenuis(Sibth.), Dactylis glomerata (L), Deschampsia caespitosa (L.), Poa pratensis (L.), Holcus mollis (L.), Arrhenatherum elatius (L.), and Juncus effusus (L.).

There are two areas of woodland, one of beech (Fagus) and another mainly of elm (Ulmus) and oak (Quercus).

There are four areas of broom (Fig. 1) within the grounds and they are described below:

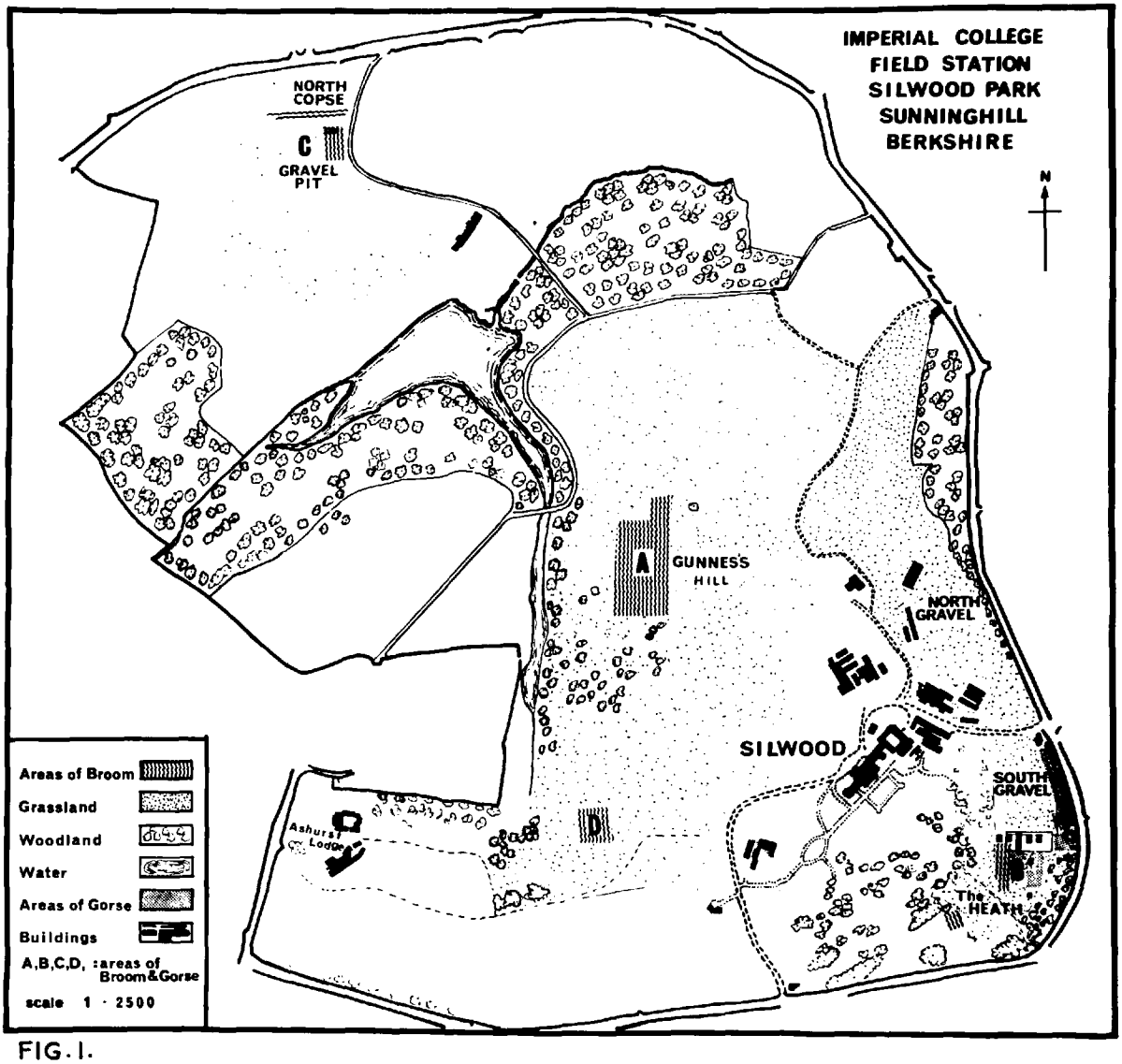

IMPERIAL COLLEGE
FIELD STATION
SILWOOD PARK
SUNNINGHILL
BERKSHIRE
N
NORTH COPSE
C
GRAVEL PIT
A
GUNNESS HILL
NORTH GRAVEL
SILWOOD
SOUTH GRAVEL
D
Ashurst Lodge
The HEATH
Areas of Broom
Grassland
Woodland
Water
Areas of Gorse
Buildings
A,B,C,D, :areas of Broom&Gorse
scale 1 · 2500

FIG. I.

Area A or "New Broom":- habitat of Piezodorus lituratus (F.) and Picromerus bidens (L.), is the largest broom plot in Silwood of 1.01 hectares (2.5 acres)(Fig. 1). This area was planted in 24 rows containing a total of 1609 broom bushes in 1957. It is surrounded on the south and west by tall trees, mainly by oak and chestnut, and on the north and east by grassland. The commonest grasses are Dactylis glomerata and Deschampsia caespitosa.

Area B or "Old Broom":- habitat of Picromerus, Piezodorus, Palomena prasina (L.), Aelia acuminata (L.), Neottiglossa pusilla (G.), and their egg-parasites. This area of broom extends over about 0.81 hectares (2 acres). The plot is surrounded on three sides by tall trees, mainly beech intermixed with oak, elm, birch, pine(Pinus) and Abies. On the north side there are some huts and relatively open grassland dominated by Festuca rubra (L.), Agrostis tenuis (Sibt.), Deschampsia flexuosa (L.), Holcus mollis (L.) and Lolium perenne (L.). This area is not only covered with broom but has a number of dense growths of Ulex europeus (L.), separated by grass and trees.

Area C:- habitat of Piezodorus and its egg parasites. This site consists of about one acre of scattered broom bushes and some bushes of gorse, mixed with bramble. It is surrounded on the north and east by trees, mainly by oak, sweet chestnut and birch, by huts on the south and by grassland in the west.

Area D:- This site is a small plot of broom of less than one acre, where 138 bushes were planted in 1958 and in 1959. The surrounding area is mainly grassland dominated by Dactylis glomerata, Poa pratensis, and Deschampsia caespitosa.

During the Spring and Summer, a considerable number of flowering plants appear among the grasses around the broom areas. The commonest of them are Carduus pratensis Huds. (Meadow Thistle), Achillea millefolium L. (Milfoil or Yarrow), Milium effusum L. (Spreading milium)Potentilla verra L. (Spring Potentilla) and Rubus idaeus (Raspberry).

The vegetation under broom and gorse dies in the shade of the bushes and accumulates as litter which serves as a hibernation site for the shieldbugs.

2. Area near Silwood Park - Site of collection of Piezodorus, Aclia, Picromerus and their egg parasites.

During this work, visits were made at different times of the year to study and to collect specimens of Pentatomoidea, and their scelionid egg parasites to areas within a radius of 20 miles around Silwood Park. These areas were mostly in Berkshire, Surrey and Hampshire. There are large areas of gorse scattered in these three counties and smaller ones of naturally growing or planted broom.

In 1965, an area called the Cricket Hill, in Yateley, Hampshire was visited regularly. The area is situated

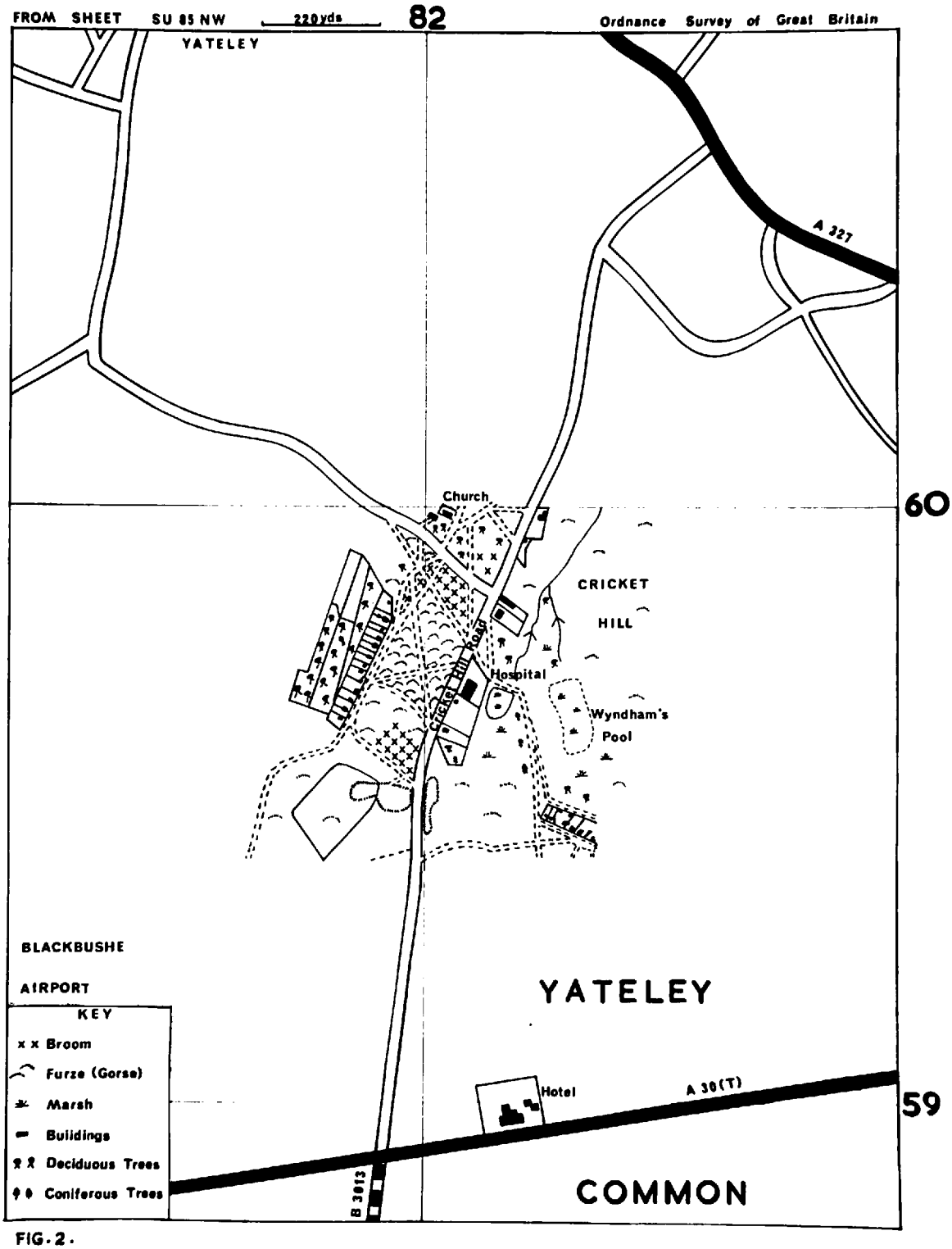

FROM SHEET SU 85 NW
220yds
82
Ordnance Survey of Great Britain
YATELEY
A 327
Church
60
CRICKET
HILL
Cricket Hill Road
Hospital
Wyndham's
Pool
BLACKBUSHE
AIRPORT
YATELEY
KEY
x x Broom
Furze (Gorse)
Marsh
Buildings
Deciduous Trees
Coniferous Trees
Hotel
A 30(T)
59
B 3013
COMMON

FIG. 2.

about 12 miles to the south-west of Silwood Park and is near Blackbush in Hampshire. There are about 2.43 hectares (six acres) of gorse and broom divided into three parts of about 2 acres each; these are separated by narrow roads. The eastern and western parts are covered with wild broom and the middle site by gorse and several scattered bushes of broom (Fig. 2 and 3).

The broom bushes on the eastern and western edges, are taller and more crowded. The area is surrounded on three sides by tall trees mainly of oak, birch. beech and by several buildings on the north and west. The southern side, however, is relatively open grassland with scattered bushes of broom and gorse. The commonest grasses are Festuca pratensis (L.), Agrostis tenuis, Dactylis glomerata, and Poa pratensis; some bramble is also scattered among the gorse and broom bushes.

The following species were collected at Cricket Hill:- Piezodorus lituratus, Aelia acuminata, Neottiglossa pusilla, Picromerus bidens, Asolcus davatchii sp.n., A. nixo-martini sp.n., A. silwoodensis sp.n., A. waloffae sp.n., Telenomus truncatus (Mayr) and T. sokolovi (Mayr).

3. Other Areas of Study.

Attempts were aslo made to find out the host plants of the Phytophagus shieldbugs in areas far away from Silwood Park and near to the sea. During 1964, 1965 and 1966 several visits were made to southern Hampshire, especially

to different sites of the New Forest and to the Isle of Wight. One visit was also made each to Scotland, the north of England (Lancashire and Yorkshire), to South Wales (Cardiganshire) and to Kent, Sussex, Dorset, Devon, Cornwall, Cambridgeshire and Oxfordshire. Generally leguminous shrubs and in particular gorse were found to be very common. However, in these areas broom was not very abundant, and grew on grassland. In the New Forest there was very little broom (e.g. In Furze Garden, Beaulieu), whereas, gorse was very common in most areas visited. In the New Forest, one area called "the Queen's Bower" was selected for further study and the following is a description of it.

Queen's Bower, New Forest, Hants.

This is an area of woodland at an altitude of 50 ft. overlying a substratum of Bracklesham Beds. These beds, at Queen's Bower are predominantly of a dark, sandy, clay. This provides a moist habitat as percolation of water down through the soil is retarded. These conditions favour the development of woodland with a relatively rich flora compared with other acidic soils (Fig. 3).

The following species were collected in Queen's Bower:- Piezodorus lituratus, Asolcus silwoodensis, Telenomus truncatus. This open, large area is surrounded by tall trees such as: Quercus robur, Fraxinus excelsior Linn., Ilex aquifolium Linn., Fagus sylvatica Linn., Taxus baccata Linn., Crataegus

Queen's Bower (New Forest)

Wisley Common (Surrey)

Cricket Hill (Hants)

Fig.3.-DIFFERENT HABITATS OF Pentatomoidea AND THEIR EGG PARASITES IN SOUTHERN ENGLAND

monogyna Jacq. The undergrowth consists of typical shade-tolerant species: e.g. of Epipactis helleborine crantz., Hypericum androsaemum Linn., Euphorbia amygdaloides Linn., Carex sylvatica Huds etc., and this is where Piezodorus and two species of scelionids, A. Silwoodensis and T. truncatus were commonly found.

Outside the limits of the woodland on dryer sandy soils, there is heathland with larger plants such as: Ulex europæus, Betula pednula, Rubus fruticosus and the smaller Holcus lanatus Linn., Luzula campestris Br., Calcuna vulgaris Salisb., Erica cinerea Linn., Plantago lanceolata Linn., and Deschampsia flexuosa.

Piezodorus lituratus and its two egg-parasites mentioned above, were very common on gorse in Queen's Bower, but the other shieldbugs such as Aelia acuminata, Neottiglossa pusilla, Palomena prasina, Eurygaster maura L. and Picromerus bidens were rare. However dense shrubland in other areas was generally found to be a suitable habitat for most Pentatomoidea and their egg-parasites.

METHODS

1. Numerical estimation in the field.

i) Beating method.

This method was used for estimating the population of the adults and larval instars of Piezodorus lituratus in area A (see page 19). The area is about one hectare (2.5 acres) of broom where 1,609 bushes were planted along 24 rows in 1957.

Since the number of individuals of Piezodorus was low, the number of samples was increased. Each sample consisted of a 100 beats from 100 different plants in the area. In each beat a quantity of broom measuring about one eighth of a bush was shaken three or four times over a cloth tray of one square metre. Beats were taken at 10m intervals, the starting point being different on each date of sampling. The shieldbugs and their larvae that fell on to the tray were counted and recorded, the adults were also sexed and were recorded. As Piezodorus and its larval instars showed most of their activity at higher temperatures, sampling was usually done during the warmer hours of the day. The broom area was sampled once a week as evenly as possible on each sampling day, by beating an equal number of bushes from each row.

This study started in June 1963 and was continued in 1964 and 1965. From April to October, during the period when Piezodorus or its larvae could be found on broom, sampling was carried out every week. The data so obtained provided results for estimation of the population of Piezodorus.

This method of sampling is systematic and covers the whole area. It has been successfully used in the study of natural populations of some other insects, such as Phytodecta olivacea (Forster), a chrysomelid beetle living on broom (Richards and Waloff, 1961).

ii) Sweeping method.

This method has been commonly used for the study of natural populations of some cereal shieldbugs, particularly Eurygaster and Aelia ssp. At Silwood Park it was used in the study of population density of Aelia acuminata in a small grass area of one hectare (2.5 acres) in the North and South Gravel (see page 65). Samples were taken once a week, by making 100 sweeps with a standard D Frame sweep net. The number of adults and larval instars collected in nets were counted and recorded. The adults were also sexed and recorded. Since the first instar nymphs of Aelia and Neottiglossa pusilla are very similar to one another and both occur at the same time in the same habitat, they were not included in the estimate of

populations. The first instar nymphs were also found mostly low down in the grasses and the number of individuals collected each time was very variable. Sweepings were made in different parts of the area and on different species of grasses on which Aelia were found. The study was carried out between May and October in 1964 and 1965. This method of sampling covered the whole area, but it involved considerable disturbance of the habitat. Hence, it was carried out at intervals of 5 - 7 days. Although sweeping is an unreliable method of sampling, it provides an index of the size of the population.

iii) Collecting shieldbugs from the overwintering sites.

Several methods have been used to estimate the shieldbugs in their hibernation quarters. Quadrat sampling, usual dimensions being 0.25 - sq.m frame (50 cm X 50 cm), and counting the insects per plant have been extensively used in the study of the natural populations of several Pentatomoidea, particularly of the well known cereal pest Eurygaster integriceps (see Fedotov, 1954; Vinogradova and Shumakov, 1958). Although this method is probably reliable in the study of the population density of shieldbugs in their hibernation quarters, it is not very easy and can be done only under certain conditions (see Brown, 1962).

In the present investigation it was intended to study the changes in the population density of Piezodorus and Aelia in their hibernation sites at Silwood. Preliminary observations were made from October 1963 to April 1964 in and out of Silwood, but were abandoned later as the number of individuals collected was extremely low. Therefore this method was abandoned at Silwood, but search for hibernation sites was continued outside this area.

2. Field rearing of the shieldbugs.

Rearing of Pentatomoidea in the field was carried out in cages differently designed to suit the insect species and the host plant. The following designs were commonly used.

Cellulose acetate cages.

These cages were constructed from cellulose acetate sheet and muslin or terylene. Acetone was found to be a good adhesive in attaching these two materials together. The cellulose acetate used was of two thicknesses; 0.5 mm and o.4 mm. The first sort was particularly useful in the constructions of cages for rearing. This celluose acetate is reported to be slightly toxic to plants (Kiechefer and Medler, 1960). It was observed that the leaves of Graminae, leaves and twigs of broom in contact with the material tended to become pale and shrivelled after 3 - 5 days; thus, the plants were usually changed after several days when it was judged to be necessary. The cages were different in form and size depending on their use in each experiment.

a) The standard size cage.

This consisted of an open cellulose acetate cylinder 25 cm in length and 8 cm in diamter. Six circular windows of 4 cm in diameter were cut in each cage and covered with muslin; (three in one row about 5 cm from each end). Two holes each 1.5 cm in diameter were made on the side, each about 10 cm from the window end of the cage. These were used for the introduction of insects or the collection of their eggs in the field and were closed with corks or bungs. One end of the cage was covered with muslin and the other end was connected with another cylinder made of muslin 15 cm in length and 8.5 cm in diameter. This cage was placed on a suitable broom bush enclosing some few ends of several twigs. The end of the muslin cylinder was securely tied round the twigs by a string (fig. 4). This form of cage was commonly used for the rearing of Piezodorus, Picromerus, Palomena and was found very suitable.

A similar cage was used for rearing pairs of adult shieldbugs. Each cage was inspected every day or on every other day if it was wet, the number of eggs, the site of oviposition were recorded and the eggs were collected. Every 7 to 8 days the insects of each cage were transferred to another clean cage and placed on fresh twigs near the first site. The

old cage was taken with its contents, by cutting the twigs about 5 cm from the tied end. In the laboratory the cage was opened on a clean tray and all leaves, pods, twigs and muslin were carefully inspected for the second time. The eggs, the site of oviposition, the dead shieldbugs and other insects in the cage were recorded.

b) Second Design.

This was constructed from a cellulose acetate cylinder open at one end, 5 cm in length and 15 cm in diameter and 0.2 mm in thickness. Two ends of a piece of muslin 30 cm in length and 45 cm in width were attached length-wise to a band of cellulose acetate 30 cm in length and 5 cm in width to form a cylinder. This cylinder in turn was attached to the open end of the cellulose acetate cylinder. About 1 cm of the materials was used in the joints making the interior of the cylinder clearly visible along the cellulose acetate band and the continuous cylinder thus formed consisted of the celluloid ring and muslin 15 cm in length and 16 cm in diameter. Three holes of 1.5 cm diameter were cut, two being on the band 10 cm away from each end and the third on one side of the closed end. These were closed with bungs or corks (fig. 4).

The cages were placed over free ends of young branches of gorse or broom and the open end of the cage tied securely round the branches with string. These cages were very useful because the temperature, humidity and probably ventilation (as there was no condensation within the cages) were found to be almost the same as the outside during warmer days. They were used for rearing of Piezodorus, Picromerus and Palomena.

c) Third Design.

This was an open cylinder 20 cm in length and 8 cm in diameter made from the thinner cellulose acetate. Windows and the holes for inspection or introduction of insects were similar to those in the standard design described earlier. The two ends of the cylinder were connected to two muslin cylinders each 15 cm in length and 8.5 cm in diameter. These cages were placed over 10 - 15 shoots of grass. The lower end was tied gently round the grass close to the ground, the other end was also securely tied. The cage was secured by string to an upright wooden pole 1.1 m high, which was firmly fixed in the ground very close to this grass. This supported the cage (fig. 4).

These cages were used for rearing pairs of shieldbugs which fed on grasses, for example Aelia and Neottiglossa. They were inspected every day or every other day and the number of eggs and sites of oviposition were recorded. The cages

were changed every 7 - 8 days, and the insects were introduced to another cage with fresh grass close to the old cage. The old cage was inspected in the laboratory as previously described.

These cages were found to be very useful for rearing the Pentatomoidea which appear on cereals as conditions within them are close to those outside.

d) Fourth Design.

This was an open cylinder constructed from the thick cellulose acetate 45 cm in length and 15 cm in diameter. One end was covered by fine terylene and the other end was connected to a cylinder of terylene 30 cm in length and 16 cm in diameter. Four windows each 20 cm in length and 6 cm in width were cut out of the cylinder, 10 cm from the covered end and were covered by terylene. Three holes were cut on the side in one row, their centres being 10 cm apart. These were used for the introduction of insects and collecting their eggs or providing larvae as food in the case of Picromerus, and they were closed by bungs or corks. The cages were placed over broom or gorse and were inspected in the same way as the standard size cages.

These cages were designed for mass breeding of Piezodorus and Picromerus as well as for rearing their larval instars and were found to be suitable.

Big cages.

These were rectangular cages 1.30 m X 90 cm X 1.40 m made of wood, 5 cm X 6 cm one side fixed by hinges forming a door. All the sides as well as the top were covered with fine muslin or terylene leaving the base free, the terylene being attached by means of wire, cellotape and drawing pins. These were designed by Mr. M. J. Way and originally used in population studies of Aphids. In the present study, they were used with a small modification on the door, which consisted of an inner sheet of muslin covering the whole area on which an entry hole 50 cm in diameter was cut, this being 30 cm away from the ground. This hole was connected to a tunnel of muslin of the same diameter and 75 cm in length. The tunnel served as a means of entry into the cage. This device was very useful in preventing the possible escape of the insects through the normal type of door. This was usually tied in a knot when the door was closed.

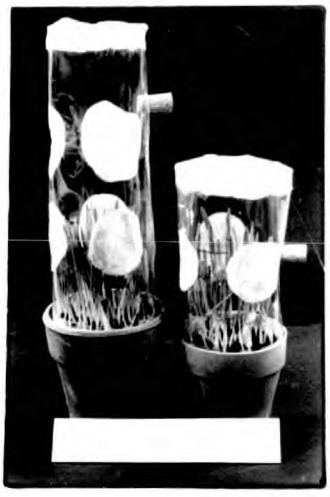
At the open end of the cage wooden boards of 15 cm height were fixed extending along the whole length of each side. When the cages were placed over the plants about 10 cm of the base was buried in the ground and the sides covered with soil. The tops of the cages were covered with thick polythene material (fig. 5; page 54).

These cages were useful since the conditions within, were nearer to those outside. They proved to be suitable in routine inspections carried out throughout the three seasons of studying the biology of Piezodorus, Picromerus, Palomena, Aelia, Eurygaster and their scelionid egg-parasites.

3. Laboratory rearing of shieldbugs.

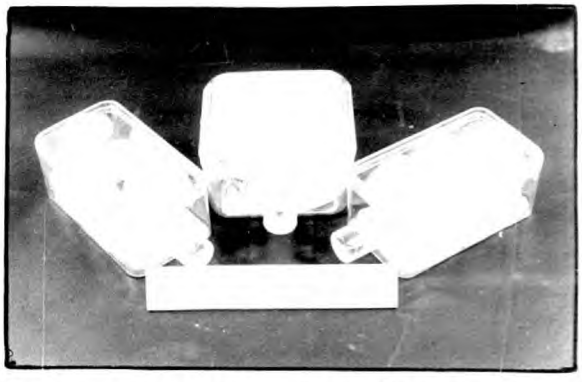
Cultures of Pentatomoidea were maintained at temperatures of 20°C, 25°C and 28.5°C under ~~constant~~ illumination in constant temperature rooms with a 16 hour photoperiod, controlled by a time switch. The constant temperature rooms were equipped with benches and overhead lighting from 6 fluorescent tubes each 75 cm in length, the tubes being placed 60 cm above the surface of the benches (the 28.5°C C.T. room, had two lighting tubes, placed about 1.5 m above the bench). There was no humidity control in the first two rooms, the humidity being around 55% R.H. The humidity in 28.5°C C.T. room, was about 70% R.H. maintained by a steam injection apparatus. The suitable humidity for breeding was found to be around 75% R.H. This was in practice maintained by culturing the shieldbugs in newly made rearing boxes. Several experiments were also done in a 15°C constant temperature room which was similarly equipped to that at 20°C. The stocks of pentatomoids were kept at 10°C constant temperature room, or at 3°C in a refrigerator, in polystyrene boxes with 3 cm of sand at the bottom, which was watered regularly to maintain relative humidity of 60 to 70%.

Celluloid cage of Second Design (Field rearing)



Laboratory breeding cages for Aelia and Eurygaster with Shoots of Cereals

Celluloid cages of Standard Design (Field rearing)



Polystyrene cages. First Design (in the middle) and Second Design

Stock cage for E. integriceps

Polystyrene cage (Third Design)

Fig. 4.—Field and Laboratory Rearing Cages Designed for Pentatomoidea

F O O D

It was desirable to study the reproductive biology and in particular, fecundity and longevity of several Pentatomoidea in relation to the different food and temperature. The test insects were Eurygaster integriceps and Aelia acuminata. Some experiments were also done on Piezodorus lituratus and the carnivorus Picromerus bidens. The food was therefore different depending on the species of insect and experiment. It is listed below:

Diet No. 1: Wheat and barley shoots.

Young wheat (variety, common British wheat) and barley (variety Proctor) was grown in plastic or clay pots containing sterile John Innes Potting Compost, in glasshouses at varying temperatures of 23°C - 27°C. The mercury vapour lighting controlled by a time switch was used in Autumn, Winter and Spring to maintain a day length of about 18 hours. About 18 to 20 seeds were sown at a depth of about one cm in the porous clay. The plants were also grown in larger pots and transplanted into small pots. When the seedlings had grown to about 15 cm the pots were transferred from the glasshouse and placed in a constant temperature room at 10°C and usually used in experiments after 5 to 10 days. A continuous supply of plants of the standard size were obtained by sowing seeds every

three or four days. The pots were regularly watered once or twice a day depending on the temperature of the room. About 15 healthy shoots were selected in each pot and the surface soil in the pots covered with about one cm heat sterilized sand just before being used. The sand was found to facilitate the routine inspection for oviposition of insect, the determination of soil humidity, and the dead insects. The standard size celluloid cylinders with a free end were fitted on to the top of the clay pots 9 cm diameter and then transferred to the constant temperature room. In this way the plants grew well under less crowded and good conditions and when the time approached to produce the third leaf, they were ready for the culture of Eurygaster, because the shoots were approaching the optimum conditions for feeding and oviposition of these cereal shieldbugs. The insects were introduced through the holes in the cages.

Two other celluloid cylinders were also designed and used in this experiment. One was a cylinder 15 cm in length and 8 cm in diameter with three windows, 4 cm in diameter and one hole for the introduction of the insects. The top end of the cage and the windows were covered with fine muslin.

The second design consisted of a cylinder 20 cm in length and 8 cm in diameter with one end covered by celluloid material. There were two windows, 5 cm in diameter, cut near the top on opposite sides, covered by fine muslin and one hole in the middle of the cage. These cages were fitted on to the top of a 9 cm porous clay pot (fig. 4).

These three designs were found to be useful. The conditions inside the cages were almost the same. In the culture room at 28.5°C they were watered twice daily in order to provide a humidity of about 75% within them. The pots of plants were replaced regularly every 3 days, and at the same time the insects were removed and weighed. The plants were inspected at least once a day, the number of eggs and the site of oviposition being recorded. The plants in the old pots were cut at the base near the surface of sand. The shoots were placed in a polythene bag for a second inspection on a clean tray as described before.

Diet No.2. Wheat and barley grain:

Those Pentatomoidea which appear on cereal or grasses, for example Eurygaster, Aelia and Neottiglossa, feed well on wheat grain, not only when they are soft during their growth and are easy to pierce, but also grain when it is dry and in the laboratory. This is known from observations on newly

emerged adults of Eurygaster and Aelia species or their last instar larvae under clumps of wheat in the field just after harvesting (see Vassiliev, 1913; Fischler 1937 - 39; Alexandrov 1946 - 48; Ouchatinskaia 1955; Jourdan 1955; Voegelé 1961; Brown 1962 - 63).

In 1960, experimental breeding of Eurygaster integriceps carried out in Varamin and Karaj laboratories in Iran indicated that this insect can be bred on dried wheat grain with water. This was continued on a mass scale from 1961 in Moharakeh station near Esfahan in central province of Iran. The eggs were used in mass scale breeding of Asolcus egg parasites which control the population of E. integriceps (see Remaudière 1960 - 62, and Martin et al 1960 - 64).

During the last 30 years different methods have been used for breeding Eurygaster and to a lesser extent of Aelia species particularly on seedlings or wheat grain. In the present work it was intended to find a suitable method of breeding Eurygaster and Aelia species in order to study the effect of different kinds of food on fecundity in relation to various temperatures. An attempt was also made to devise a method of rearing the larval instars of shieldbugs.

Four designs made from three different sizes of polystyrene boxes of 2mm thickness were used. These boxes were ventilated by 2.5 cm diameter holes cut in their lids and sides by means of heated glass tubes 2.5 cm in diameter. The open end of the tube was heated on a strong flame for several minutes until the glass became red hot and this end was then pressed on to the polystyrene a hole being thus formed. It was necessary to change the tubes after about ten cuts, as the whole tube became hot and hence difficult to handle; and also because the glass became sticky. In each box a hole on the side was needed to fit in a horizontal tube of about 2.4 cm in diameter and 7.5 cm in length, containing water. The open end of this tube, within the cage, was covered firmly with hydrophil cotton wool. The ventilation holes were covered by terylene. The following cages were found suitable and were commonly used in culturing the shieldbugs (fig. 4).

a) <u>The First Design</u>.

These were 11 cm X 11 cm X 6 cm polystyrene boxes ventilated with 4 holes on the lid and 3 on the sides. A tube containing water was placed in a hole on the side. The tubes of water provided approximately 75% R.H. within the cage, and access to drinking water which was sucked through the cotton wool covering the open end of the tube. The inside bases of boxes

were covered with fine muslin. This helped the animal to regain its normal position when it fell on its back. A piece of cardboard 5 X 4 cm was cut into 4 strips 3/4 of the way up to the top. Strips were bent to left or right alternately and the whole roof-shaped structure stood 4 cm high. These roof-shaped structures were put into boxes for oviposition (fig. 4). The width of the strips was found to be suitable for the female to grip during the act of oviposition. The cereal shieldbugs were provided with water and wheat or barley grains. The grain was attached to the roof-shaped cardboard by a paste formed of flour of the same variety as the cereal.

These cages were used for breeding Eurygaster integriceps, Aelia acuminata and Neottiglossa pusilla. The cages were inspected every day and the eggs collected. The number of eggs and the sites of oviposition were recorded. Every three days the insects were weighed and transferred to fresh cages. Every five days the cages were washed in a detergent diluted in warm water of about 45°C. This type of cage was usually used for rearing a pair of insects and conditions within it proved to be suitable.

b) Second Design.

These cages were constructed from polystyrene boxes 7.8 cm X 13.8 cm X 5 cm, with 3 holes on the lid and 5 on the sides. One hole on a short side being used to hold a tube of water of the standard size. These sorts of boxes were made of polystyrene which was clearly transparent and strong enough for continuous routine experimental culturing under different conditions. The bottom within the cages were covered with muslin. One or two roof-shapes of cardboard were supplied for oviposition as described earlier.

These boxes were used for breeding all six species of shieldbugs. The food provided depended on the species of Pentatomoidea and on the experiment; for example the cereal shieldbugs such as Eurygaster, Aelia and Neottiglossa were fed on grains of wheat, barley or oats, attached to pieces of cardboard by paste made of flour of the respective grains as described in the first design. Four to five fresh twigs of broom of about 12 cm in length or, occasionally, gorse with buds or pods were used in breeding of Piezodorus or Palomena. Each twig usually had 4 - 5 pods or ten buds. These twigs tied in a bunch were placed in cotton wool to form a plug and were inserted at the open end of the horizontal tube containing water. In this way the plant was kept fresh for two to

three days after which it was changed or the shieldbugs were transferred to fresh boxes. The boxes were inspected daily and the eggs collected. The number of eggs and the site of oviposition were recorded. The old twigs were always placed in polythene bags and inspected for a second time.

c) Third Design.

This consisted of larger polystyrene boxes of 12 cm X 24 cm X 6 cm. Nine windows each 2.5 cm in diameter were cut with a standard tube on the lids and 6 on the sides. They were covered with terylene. Two tubes of water were fitted either to two holes on one of the long sides or one to each of the short sides. The interior of the cage was provided with a sheet of muslin and five to six roof-shaped pieces of cardboard with grains of wheat, barley or with fresh twigs of broom, as described previously.

These cages were designed for culturing five to ten pairs of shieldbugs or for rearing up to 50 of their larvae. They were used for breeding all the six species of shieldbugs. Sufficient food was always provided depending on the number of insects within the cage. The cages were inspected twice daily, the eggs being collected and the number of eggs and the sites of oviposition being recorded. Fresh cages were used every three days. These cages were found to be useful for mass breeding and rearing of shieldbugs.

d) The stock cages for shieldbugs.

These were opaque polystyrene boxes of 22 cm X 30 cm X 20 cm which are usually used in storing bread. Two windows, each 5 cm X 10 cm were cut on the lid and covered with Saran plastic Gauze attached by Xylene, Acetone, or Ethyl acetate. The floors of these cages were covered with sterilised sand about 3 cm in depth and regularly watered to provide a humidity around 65% within the cages (see fig. 4). Ten to 15 twigs, each 20 to 25 cm in length were placed within the cage and fixed in sand, and these served as supports for the insects.

These cages were usually kept at 10°C in the constant temperature room. The Pentatomoidea particularly Eurygaster were kept for five to eight months under these conditions and were used for various experiments.

3) Breeding of the Carnivorous species.

Breeding of Picromerus bidens was carried out successfully in polystyrene boxes as described earlier with small modification of the lid. One hole on the lid was used for introducing the food and was usually covered by a polythene bung or a cork. The food consisted of larvae of Tenebrio molitor L. Pieris brassicae and Plodia interpunctella H. During the period of breeding the stocks of these larvae were sometimes

in short supply and on such occasions Picromerus was fed mostly with lepidopterous and coleopterous larvae collected in the field. The eggs were mostly deposited on the inner side of the roof-shaped pieces of cardboard and occasionally on the tops of the cardboard and also on the under surface of the sheet of muslin. They were inspected daily in the usual collection and recording of the eggs and of oviposition sites. The fresh food was provided every three days and fresh cages were used every five days.

Generally the three designs proved to be suitable for breeding the six species of Pentatomoidea. They were also found to be useful in breeding Coreus marginatus (Coreidae). It seems, therefore, that they could be used for breeding of other species of shieldbugs.

4. Method of rearing.

Rearing of six species of Pentatomoid larvae in the laboratory was carried out successfully during this study. The three cereal feeders Eurygaster integriceps, Aelia acuminata and Neottiglossa pusilla were reared on wheat and barley grain. Piezodorus lituratus larvae were reared on twigs of broom with pods. Palomena prasina on cereal grain and pods of broom and Picromerus bidens larvae on immature stages of different insects,

mostly those of Lepidoptera and Coleoptera. In all six species the first, second and third instar larvae were reared in polystyrene boxes designed for the breeding of the adults, but the lids of the rearing boxes did not have any ventilation holes, therefore the humidity within the cages was higher (about 78 - 80% R.H.), this being necessary for survival of the early instar larvae of shieldbugs. Generally temperature of about 26 to 28°C was found to be suitable for breeding and rearing cereal bugs and that of 23 to 25°C for Piezodorus and Picromerus. It was however necessary to rear the early instar larvae of these insects at a high humidity as they are very sensitive to dry conditions in which many of them die. Rearing under crowded conditions was also found to cause high mortality; particularly in the later instars.

S E C T I O N 1

B I O L O G Y O F S O M E P E N T A T O M O I D E A

(HEMIPTERA - HETEROPTERA)

The following species of shieldbugs are discussed in this section:-

Aelia acuminata (L.)

Eurygaster integriceps Put.

Neottiglossa pusilla (G.)

Palomena prasina (L.)

Piezodorus lituratus (F.)

Picromerus bidens (L.)

STUDIES OF THE OVERWINTERING PERIOD IN PENTATOMOIDEA

This part describes the observations on the ecology and biology of the shieldbugs after their dispersal from their breeding areas until their emergence from the overwintering sites and flight to the breeding field in the following season. During this period the adults of both sexes of the phytophagous species were found to aestivate and to hibernate for about nine months; this time is referred to as the overwintering period of these insects.

A great deal of work has b en done in the study of the overwintering period of some shieldbugs, mostly those which damage crops. For example, valuable knowledge is available on Eurygaster integriceps. In Iran, this pentatomid usually leaves its breeding areas in early summer and migrates about 20 km to the mountains where most of the insects aestivate, on the northern slopes at an altitude of 1,900 , to 2,600 m under different species of plants, like Verbascum, Artemisia, Astragalus, Jurinea species for about three months. In Autumn they migrate to the southern slopes of a lower altitude of 1,500 m to 2,000 m on the same mountains and hibernate mostly under the last three species of plants mentioned above, until the end of winter. When the temperature rises to about 18°C,

they migrate again to the fields and produce another annual cycle (Alexandrov 1947 - 49; Martin et al 1960 - 64; Brown 1962). Aelia acuminata has been reported to overwinter on the mountain and also on the margins of the woodlands, in forests, under dead leaves of leguminous plants. It has been found with other shieldbugs like Eurygaster, Palomena, Piezodorus and Dolycoris and some other Pentatomoidea (Tischler 1937 - 39; Jordan 1955). Boselli (1932), studied some species of shieldbugs at Ucria in Sicily and reports that P. lituratus, P. prasina, A. acuminata and some other Heteroptera overwinter under Erica, Cistus, Ginestra, Disa (Ampelodesmos tenax), Hebichrisum italicum. He has also observed that Palomena and Piezodorus aestivate on the chestnut and pine trees near their breeding areas before migrating to their hibernation sites. Tischler (1937 - 39), studied some species of cereal Pentatomoidea in southern Germany and reported that Aelia hibernates under Festuca ovina. He also observed that other species of shieldbugs such as Eurygaster, Palomena, Dolycoris and Carpocoris hibernate under leguminous plants, dead leaves and under bushes. He says that cereal Pentatomoidea prefer very acid, dry, sandy slopes covered by graminaceous plants and bushes near woodlands. There is much literature on the overwintering

period of Pentatomoidea under different microclimatical conditions and in different habitats (see Puchkov, 1961, 1965).

In Britain very little is known of the ecology and biology of Pentatomoidea and in particular of their overwintering period (see Butler, 1923; Southwood and Leston 1959). In the present study an attempt has been made to investigate this period in the five species of British shieldbugs of which, both sexes of A. acuminata, N. pusilla, P.lituratus and P. prasina, overwinter as adults and the carnivorous P. bidens in the egg stage. Some observations, however, were also made on E. integriceps which were kept in big cages in the field in 1964 and 1965. A brief account of observations of the overwintering period of these shieldbugs is given in their section. Other aspects of their biology are discussed later.

a) Distribution of the overwintering sites of shieldbugs.

Of the five species of British Pentatomoidea studied, P. lituratus was found to have the widest distribution and was very common in southern England. It was collected under grasses or on its host plants in and around Silwood, in Yateley and in almost all areas of the New Forest (Hampshire), Wisley (Surrey) and in Badger's Mount areas in Kent. It was also collected on grasses in the Isles of Scilly in August

1965 by Mr Woodroffe (personal communication). A. acuminata was found at Silwood and Yateley under Festuca rubra and Agrostis tenuis in the undergrowth of gorse, broom and bramble bushes. The eggs of P. bidens were found on twigs of broom and gorse near the ground at Silwood and Cricket Hill in Hampshire in November 1964 and February 1965. Palomena and Neottiglossa were not found in all the overwintering areas studied. This probably may be due to the fact that their numbers are very low even in the breeding areas in June and July. They are, however, reported to overwinter as adults in and around the habitats in which they breed (Butler 1923; Boselli 1932).

The other Pentatomoidea collected in their hibernation sites were a female of Dolycoris baccarum found under grasses forming the undergrowth of broom and gorse near Newquay in Cornwall on 27th of March 1964. On 11th April 1965, one female of Eurygaster maura was also collected on grasses in Ranmore Common (Surrey) in a rather sluggish condition.

Generally, three seasons of regular observations on either overwintering sites, or on the reproductive phase in the field indicated that the five species of shieldbugs have widely distributed overwintering sites at altitudes between

15 to 20 m in the southern Thames Valley, particularly in central counties, such as Berkshire, Hampshire and Surrey and also in Kent. They seemed to prefer south facing sandy slopes with some broom, gorse or clumps of bushes with an undergrowth of leguminous plants, preferably herbaceous species and accumulation of plant debris under the bushes.

b) Description of overwintering areas.

1. Biotic factors.

The vegetation was of particular relevance to the present study and was investigated as far as possible. Several areas such as Yateley and the New Forest, were visited frequently. One visit each was made to northern England - Lancashire and Yorkshire, Scotland (Central and southern counties), South Wales, Dorset, Devon, Cornwall, Wisley, Kent and the Isle of Wight. The graminaceous plants in the hibernation sites were mostly Dactylis glomerata, Deschampsia flexuosa, Poa pratensis, Agrostis tenuis, Arrhenatherum odoratum and Festuca ovina. These grasses formed the undergrowth at the bases of gorse, broom and bramble bushes and formed suitable sites for shelter of the overwintering adults of Pentatomoidea. These grasses usually die by the end of summer; their leaves and stems accumulate and produce litter

preferred by the shieldbugs in their overwintering period. All the shieldbugs collected in these areas were sluggish and were found at the bases of grasses when the grass temperature was below 10°C. Piezodorus, however, was found several times on the top of the broom and gorse twigs on sunny days of January 1964 and February 1965.

Fig. 5; Area B during winter, showing broom, gorse and grasses covered by snow. The shieldbugs overwintered near the bases of the grasses under the clumps of gorse in and out of the cage.

2. Climatic factors.

Climatic conditions under which the shieldbugs lived in the three years 1963 - 65 are summarised in Table 1 which gives the average monthly temperatures and relative humidity and the total radiation and rainfall for each month. These figures were obtained from the continuous recordings which are made at Silwood Park. More information on the climatic factors is given in the appropriate parts when necessary.

a) Temperature.

The maximum and minimum air temperatures have been taken from the chart of the thermograph placed in a Stevenson screen 1.5 m above the ground. The temperature of the grass was taken at 9 - 11 am daily by placing a pocket thermometer of about 3 cm among the leaf litter between grass. This recording was important as it is nearest to the temperature which the shieldbugs experience in their hibernation sites. Figure 6 is a graph which shows monthly maximum and minimum air temperatures for the three seasons (1963 - 65) of this study.

Temperature was found to be a very important factor in determining the activity of the Pentatomoidea. The effects of temperature on the biology and ecology of many shieldbugs in their overwintering sites have been reported

TABLE 1.

AVERAGE MONTHLY CLIMATIC FACTORS AT SILWOOD PARK

Date	January	February	March	April	May	June	July	August	September	October	November	December	Average
	Temperature °C (Mean)												
1963	- 2.8	- 2.0	6.0	8.2	10.5	14.4	14.2	15.0	12.8	11.1	8.0	2.5	8.151
1964	3.0	4.4	4.3	8.0	12.8	14.2	16.9	15.9	14.0	8.5	7.7	3.8	9.458
1965	3.5	2.8	5.1	7.5	11.6	14.1	14.2	14.9	12.1	10.5	4.4	4.9	8.800
	Radiation - M.W. h/cm^2 (Total)												
													Total
1963	1.524	3.413	5.754	7.741	10.711	10.837	11.074	8.466	5.779	3.517	1.845	1.187	5.987
1964	1.278	1.913	3.463	6.765	10.649	9.373	11.350	9.436	7.060	4.533	2.044	1.463	5.777
1965	1.901	2.414	5.920	7.358	8.902	10.183	8.894	9.134	6.221	4.557	2.458	1.875	5.818
	Relative humidity % (Mean)												
1963	85	82	80	79	75	76	76	78	78	80	79	80	79.000
1964	88	84	77	81	79	77	75	73	73	83	86	85	80.083
1965	87	83	82	83	79	80	84	83	82	86	85	84	83.166
	Rainfall in mm (Total)												
													Total
1963	5.8	11.7	88.3	49.3	45.3	7.7	36.7	68.8	70.3	56.0	111.6	19.8	47.608
1964	18.7	19.6	115.0	81.5	51.2	106.4	24.4	32.9	15.4	28.3	40.8	42.7	48.075
1965	52.9	7.0	58.2	36.5	41.8	46.2	72.4	60.9	104.5	11.5	78.7	90.6	55.100

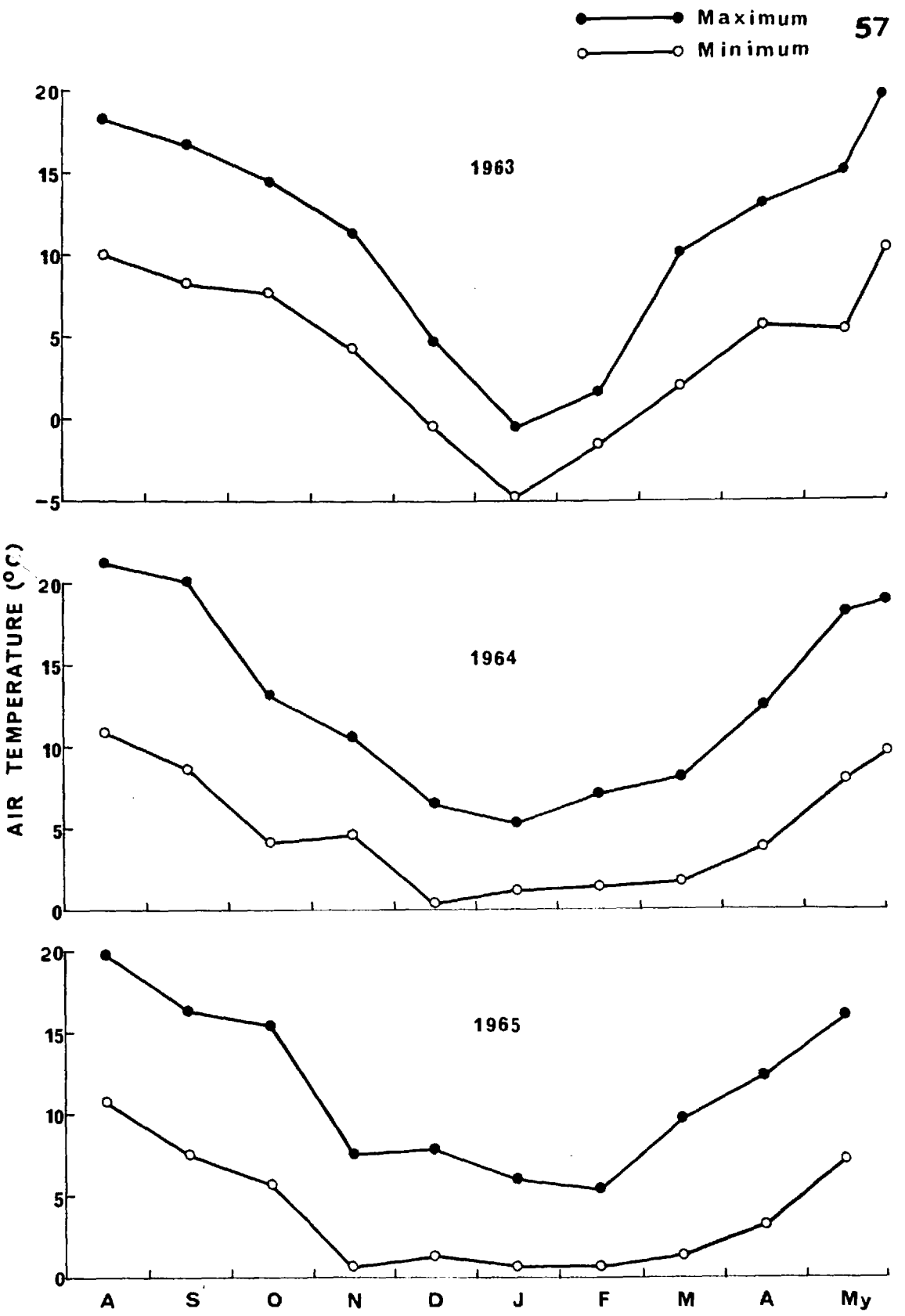


Fig. 6.— Average maximum and minimum air temperature in three seasons

by most of the authors mentioned earlier. For example (Johnson, W.F. in Butler, 1923) says that Piezodorus has been observed on its host plants during sunny and warm days in winter. At Silwood Park, Piezodorus was seen several times on broom in January 1964 and in February 1965. It was interesting to observe this pentatomid climbing slowly on the branches of broom especially on the sides which received maximum radiation, even when the ground was covered by snow to about 8 cm in depth. At midday on the same period the ground temperature was 3°C and the air temperature around the insect was 9°C. However, generally these insects are inactive below 10°C. Boselli (1932) also reports that during the sunny and warm days of winter Piezorodus and Aelia climbed to the top of the grass from their hibernation sites at Ucria in Sicily. Tischler (1937-39) studied the overwintering areas of cereal shieldbugs at East Prussia and Molln areas in southern Germany and has observed Eurygaster and Aelia on dry stems of Festuca ovina and even flying on warm days during the winter. Observation on E. integriceps by Vassiliev (1913) Fedotov (1947-60) Aronol'di(1955) Martin et al (1960 - 64) Brown (1962) all speak of the increased activity of shieldbugs in their overwintering sites when the temperature rises.

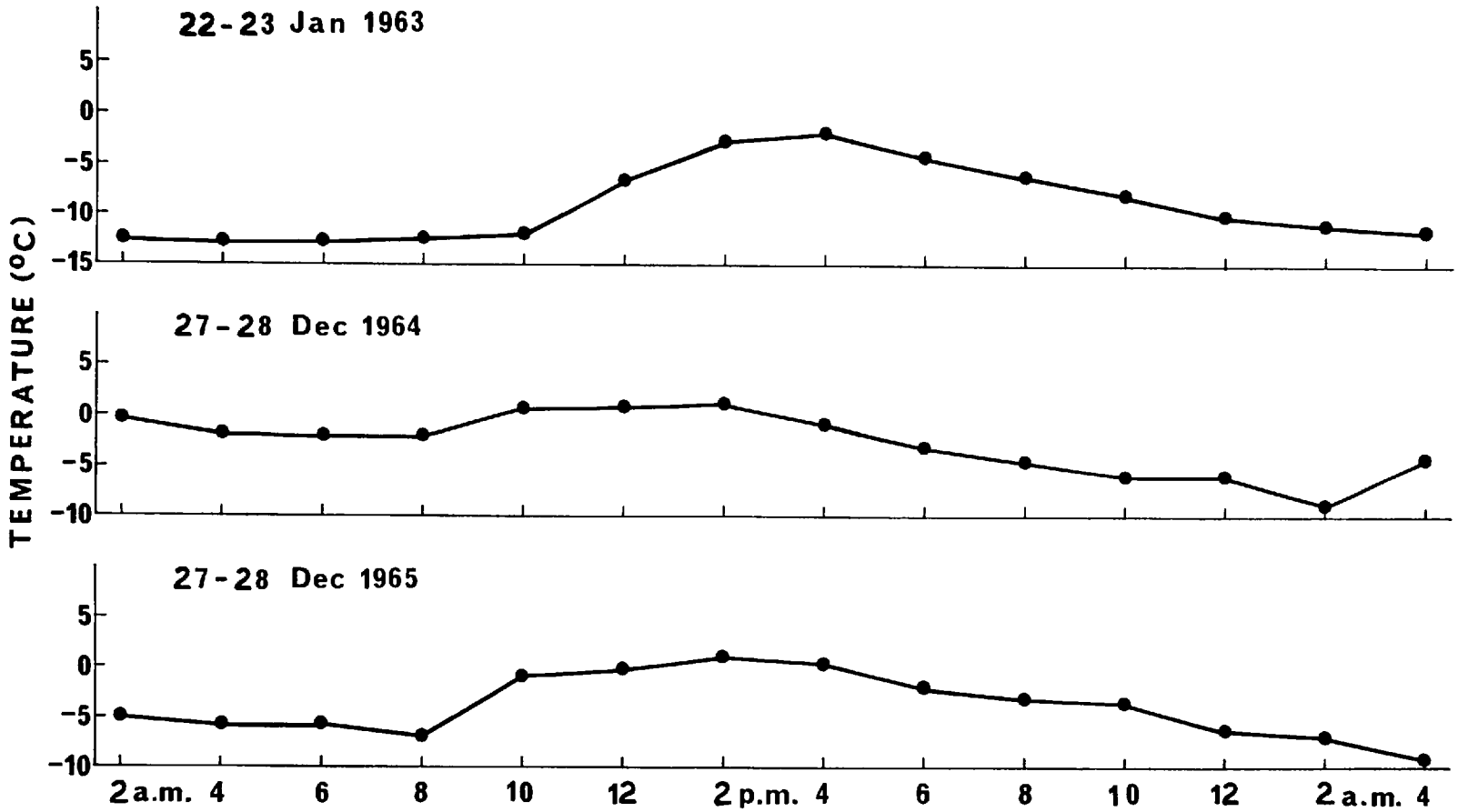


Fig. 7.— Minimum air temperature in 4 hours on the coldest dials of the winter of 1963-1965

Field observations in the overwintering sites were made once a week throughout the overwintering period in the three successive years of this study. Large numbers of the six species of shieldbugs were kept both separately and together in big cages with wooden frames covered by muslin, placed over broom and gorse bushes and over grass. The effects of temperature on the activity of these insects were observed both in the cages and outside them.

It was found that the activity of the shieldbugs during their hibernation was primarily determined by temperature near the ground. Fig. 8 shows graphs of both air and grass temperature. The latter is derived from single daily readings taken between 9 and 11 am. It can be seen that temperatures below zero occur between December and March (see also fig. 7). Changes in temperature determine the aestivation period of phytophagous shieldbugs from August to October and also the length of their hibernation period in the grasses from October to April or May. Observations made in the three seasons indicate that these insects hibernate at temperatures below 10°C.

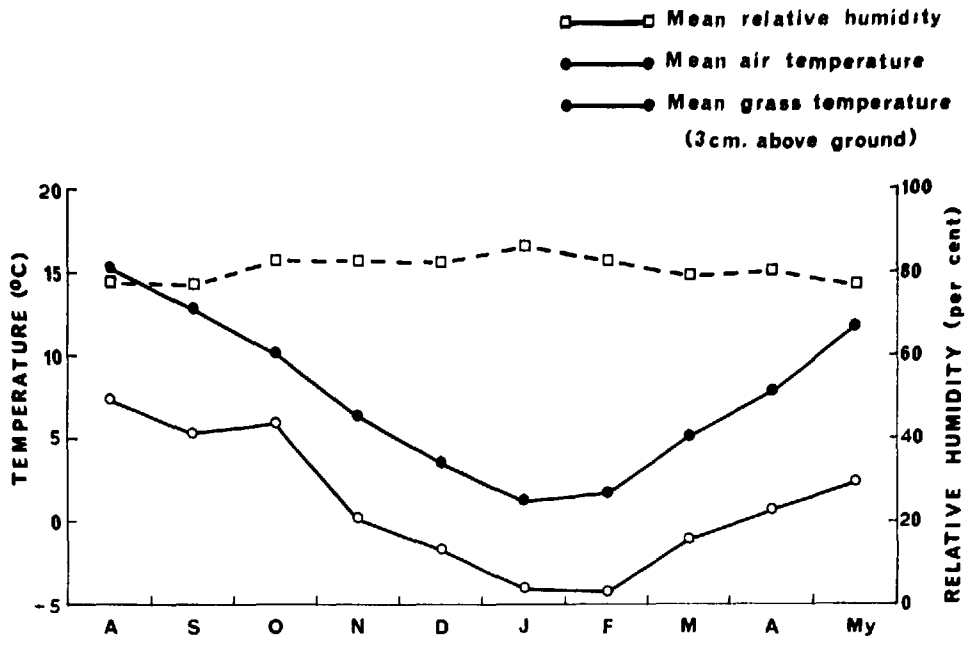


Fig.8.— Mean of air, grass temperature and the relative humidity in three seasons (1963 - 65)

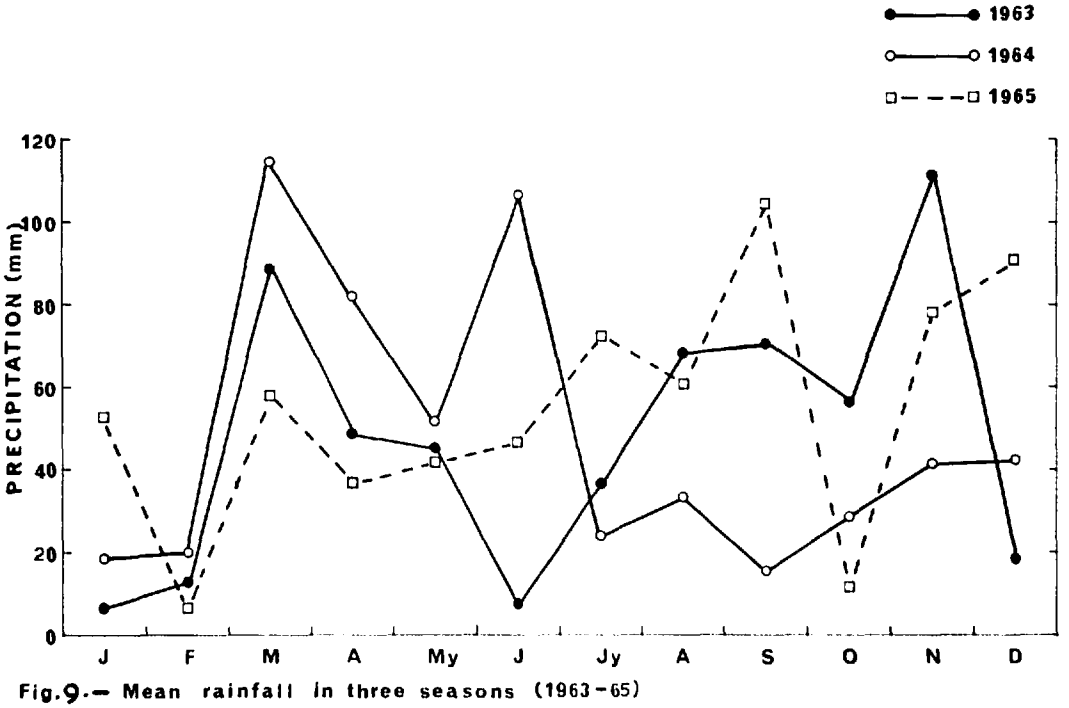


Fig.9.— Mean rainfall in three seasons (1963-65)

b) Relative humidity.

The monthly average for the three years are summarised in Table 1 and the mean relative humidity for each month in the three years is given in fig. 8. Relative humidity in grass near the ground was generally higher than that of the air above. Thus the graph in fig. 8 is only an approximation and lower humidity was experienced by the overwintering shieldbugs.

3. Other climatic factors.

a) Rainfall.

The average rainfall in the three seasons during the overwintering period of Pentatomoidea can be seen in Table 1 and fig. 9. The graphs show a minimum in February and the maximum in March. The rainfall is probably important during the aestivation period from August to October. Observations indicated that shieldbugs usually leave their aestivation sites after a period of rain in October, and go to their hibernation quarters on the ground after a period of wet weather. It was seen at Silwood and Yateley, that Piezodorus and Aelia mostly aestivate on tall trees throughout August and September and later migrate to their hibernation sites in October. The effect of rain on the biology of E. integriceps

is known in Iran. This pentatomoid leaves its aestivation site at a high altitude of about 2,200 m and migrates to a lower altitude of about 1,800 m of the same mountain after a period of rain and cold weather in October; Alexandrov (1947-49), Martin et al. (1960-64), Brown (1962). Rain during the hibernation period may cause high mortality when the ground becomes frozen, particularly in March. Snow may also cause death in shieldbugs when it melts and freezes on the ground surface mostly at the end of the hibernation period. This was observed in all the five species of Pentatomoidea kept in cages at Silwood.

b) Radiation.

At Silwood the total solar radiation was measured in milli-watt hours per square centimetre. The effect of insolation in stimulating the activity of the shieldbugs has been pointed out by many workers (see Butler 1923 and Boselli 1932). Tischler (1938) reports from southern areas in Germany that after a period of cool days when the temperature rose in May and the sun was shining Aelia and Dolycoris could be seen sitting facing the sun; their dorsal surfaces directed towards maximum insolation while the head pointed towards the ground.

It was also observed at Silwood that Piezodorus climbed on to broom on sunny days throughout the winter when the air temperature was above 10°C and that of the soil about 8°C. It sat towards the sun with its head pointing downwards when it was on twigs of broom or gorse and head pointing upwards when it was on short grasses near the ground. Aelia was seen climbing on to the tops of the cages and twigs of broom or grasses on sunny days in March 1964 and in April 1965. On 15th of May, 1965, at a temperature of 19°C Piezodorus and Aelia were seen in Yateley, emerging from the ground and climbing on to the tops of grasses. They usually sat facing the sun, exercised their wings repeatedly and then flew upwards landing on broom or on grasses near their sites of emergence. Some of them flew long distances and could not be followed. Several times they were seen to fly more than 100 metres when the air temperature was below 20°C and the weather calm.

c) Wind.

The shieldbugs were more active on sunny and calm days. They did not show any activity on windy days even when these were sunny. On many occasions they appeared on their host plants or grasses when the weather was calm and warm, but they always retreated to their hibernation sites when the wind became stronger and remained there until conditions changed.

Aelia acuminata (Linnaeus)

1. The habitat.

The area chosen to study this pentatomid at Silwood Park is called the "North Gravel." There Aelia is common, particularly on the site of North Gravel. Some observations were also made on other grassland areas within and around Silwood.

a) North Gravel (Fig. 1):

This area is about 750 feet (228.6m) long and 250 feet (76.2 m) wide and is situated on the south-east side of Silwood on rough grassland. Dactylis glomerata, Festuca rubra and Agrostis tenuis are the commonest grasses, each being locally dominant, while the following species also occur:- Agrostis gigantea (Roth.,) Holcus mollis, H. lanatus L., Poa trivialis L., P. pratensis L., Lolium perenne, Agrostis stolonifera L., Bromus mollis agg. Other common plants are: Urtica dioica L., Cirsium arvense L., Plantago lanceolata L., Ranunculus acris L., Taraxacum officinale Weber, Rumex acetosella agg., R. crispus L., R. acetosa L., Veronica chamaedrys L., Trifolium spp., Vicia sativa L., Cerastium vulgatum L. and Anthriscus sylvestris L. (fig. 10).

b) The South Gravel (Fig. 1):

This area consists of about 1.21 hectares (three acres) of grassland surrounded on east and west by tall trees

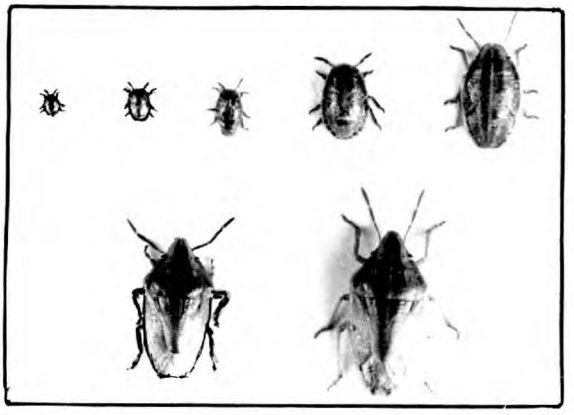
mainly by beech, birch, oak and elm. On the south it is bounded by huts. The grass species on this area are rather similar to those on the North Gravel, Festuca, Agrostis, Dactylis and Lolium being the most common and dominating the eastern and northern sides.

2. The host plants.

At Silwood Aelia occurs mainly on Festuca rubra, Poa pratensis, P. trivialis, Lolium perenne, Agrostis tenuis, Bromus mollis, Arrhenatherum elatius and Dactylis glomerata. It has also been recorded on many other graminaceous plants (see Tischler 1937, 1939; Puchkov 1961; Voegelé 1961; Brown 1962). In southern England the overwintered adults of A. acuminata are found on grass sometimes in May or at the beginning of June. At this time the graminaceous host-plants are just approaching their flowering period. Aelia attacks the young green shoots, and causes death of the terminal buds. Later, after the flowering period, the adults and larvae of Aelia turn their attention to the grains which by then are soft and milky. The extent of damage varies in different species of the grasses, but when heavily attacked, the host-plants may be largely destroyed.

Festuca rubra, Poa pratensis, Agrostis tenuis, Dactylis glomerata are common in the British Isles and have a very wide distribution throughout Europe and Asia (Thomas and

(top row) Damage on wheat grains
(bottom row) Healthy wheat grains



Larval instars and a pair of adults
Female (bottom right)

Photo: J.Voegelé

Aelia in oviposition

North Gravel – Habitat for studying Aelia and Neottiglossa

Fig.10- AELIA ACUMINATA (L.)

Davies, 1952). Aelia acuminata has a wide distribution throughout the greater part of the palaearctic region and is found in the Asiatic, European and African regions (Butler 1923; Tischler 1937, 1939; Puchkov 1961; Voegelé 1961; Brown 1962). Aelia occurs throughout Britain but mainly in the southern part below the Thames (Butler 1923).

3. Description of stages

Descriptions of adults, egg and larval stages have been given by several authors (see Tischler, 1938; Wagner, 1960). Fig. 10 shows different stages of A. acuminata taken from the newly killed materials collected in the field.

4. Occurrence of Adults

At Silwood Park and Yateley the overwintered adults of A. acuminata appeared in the field towards the end of May and the beginning of June in 1965 and 1966. The occurrence of the adults was usually observed when the soil temperature near the bases of the grasses rose to about 15°C and that of the air to about 20°C. During calm and warm days, the bugs emerged from the base of the grasses and climbed on to the top of their green stems. They sat there for several minutes, and then flew a distance which varied between 5 - 100 m to the same or to the nearby graminaceous field.

At Silwood and Yateley A. acuminata was mostly attracted by Festuca, Poa, Lolium and Bromus spp. During the

cold weather and particularly at periods of rain in May and June, the bugs were observed near the bases of grasses. The soil temperature, however, was very important for their reappearance on the grasses. This occurred when the temperature near the base of the grasses reached about 13°C. Figure 11 depicts the relationships between the temperature and the occurrence of Aelia on tops of grasses in 1965 at Silwood.

5. The Number of Adults and Larval Stages of A. acuminata

Figure 11 shows the curve of adult overwintered males, females, larval stages (1st instar has been omitted because of its confusion with N. pusilla) and the adults of the new generation caught by 100 sweeps in the field in 1965. The number of Aelia found at any time on grasses was greatly influenced by the prevailing air and soil temperatures; the bugs tend to stay near the bases of grasses during cold periods. As seen in fig. 11 the peak of the curve is in early June when the temperature rose after a cold period at the end of May. The number of larval instars and the adults of both sexes was much lower in 1964 and not more than three specimens at a time were collected in July.

Population estimation derived by sweeping is considered to give the number of bugs above the ground and to sample only the individuals sitting at the tops of the plants (Banks and Brown, 1962). Hence only an index of abundance of population

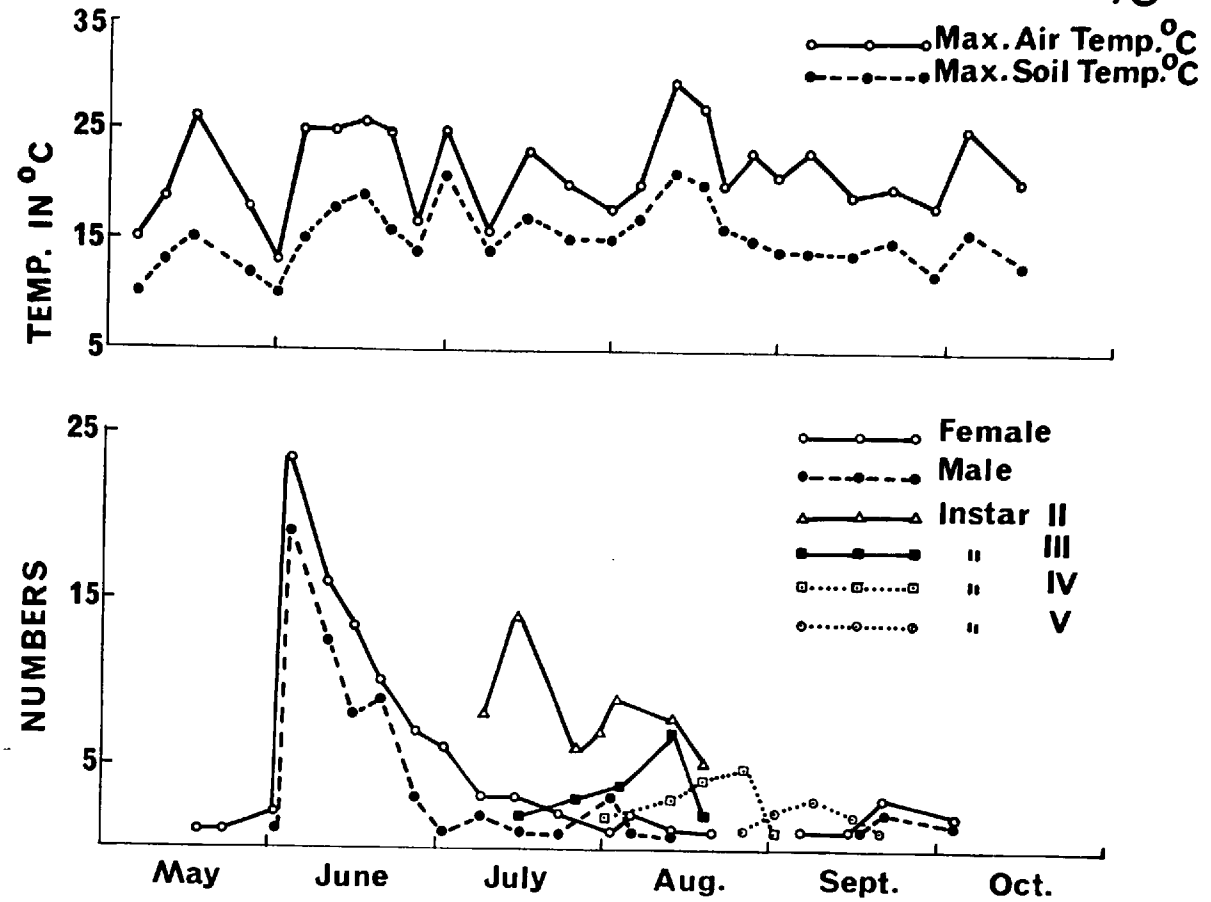


Fig.11.—ADULTS AND LARVAL INSTARS OF Aelia acuminata CAUGHT BY 100 SWEEPS ON NORTH GRAVEL 1965

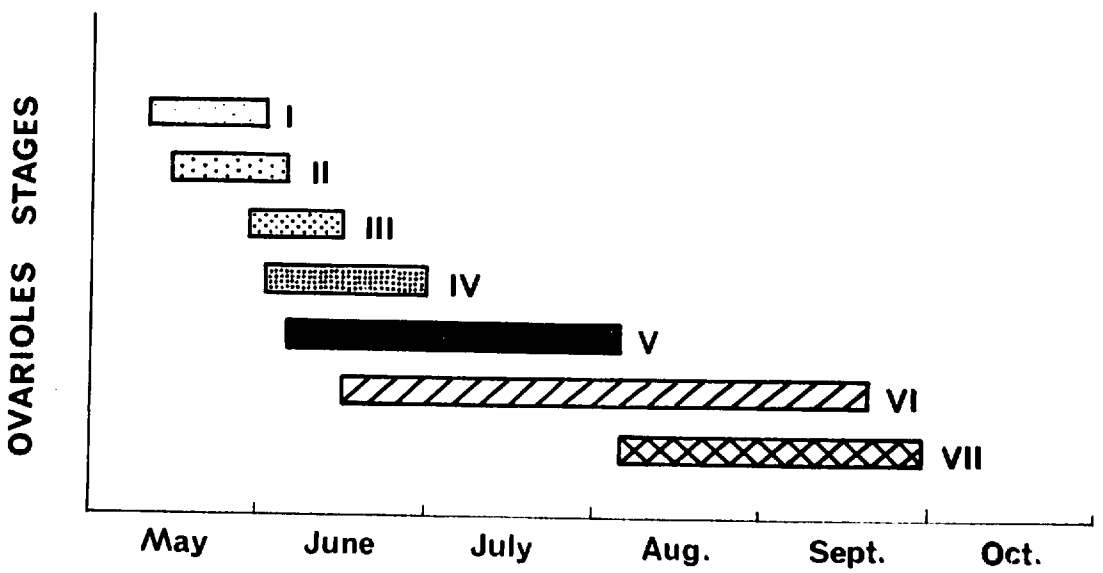


Fig.12.-STAGES OF OVARIAL DEVELOPMENT OF Aelia acuminata IN THE FIELD IN 1965

of Aelia on North Gravel was obtained.

6. Reproductive biology

A) Reproductive Organs.

a) Female: (fig. 13)

These consist of a pair of pale ovaries, each having six ovarioles, which unite into the calyces of rather short lateral oviducts and open into the common oviduct. The anterior parts of the ovarioles consist of threadlike filaments, and usually all the ovarial filaments of each ovary are united distally. The common oviduct ends in the vagina. A samll spermatheca, opens into the vagina almost at its opening.

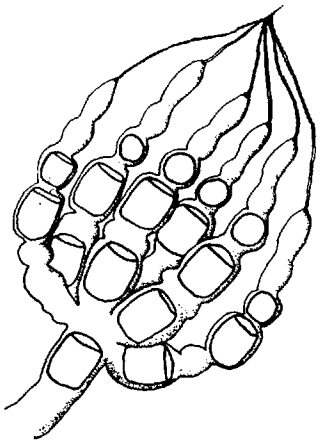
b) Male: (fig. 13)

The male reproductive system includes a pair of ovoid testes, which are reddish in colour and open into vesicula seminalis through the vasa deferentia. There is also a pair of colourless accessary glands which open into the vesicula seminalis. This is connected to the narrow tube of ductus ejaculatorius and ends in the penis. The latter part is seen between two heavily chitinised parameres which are apparently used during copulation. The sperm is produced in the sperm tubes of the testes.

7. Sexual Maturation

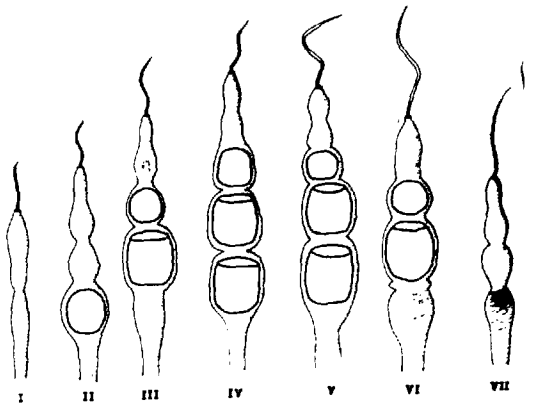
a) Diapause:

Aelia acuminata is a univoltine species in southern

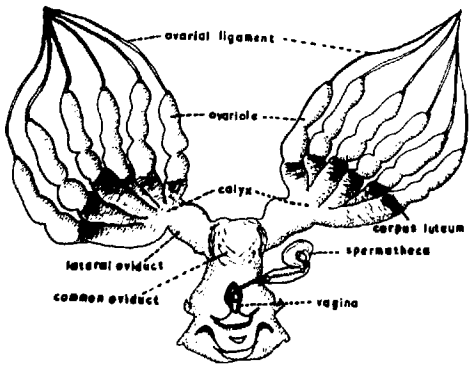


MATURED OVARY

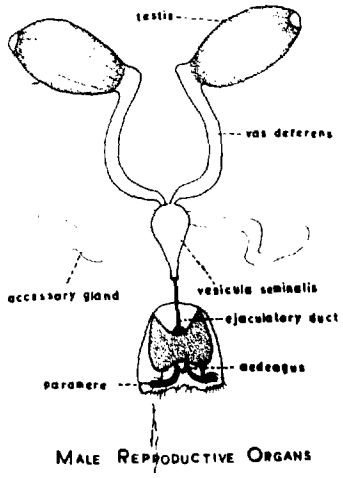
STAGE IV ; SHOWING DEVELOPMENT OF 2 EGGS IN OVARIOLES AND ONE EGG IN LATERAL OVIDUCT



DIFFERENT STAGES OF OVARIAL DEVELOPMENT



FEMALE REPPODUCTIVE ORGANS IN POST OVIPOSITION PERIOD



MALE REPPODUCTIVE ORGANS

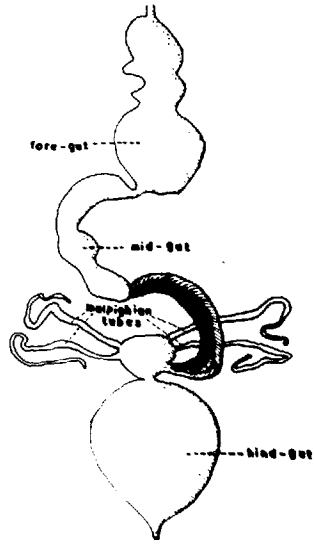


DIAGRAM OF ALIMENTARY CANAL

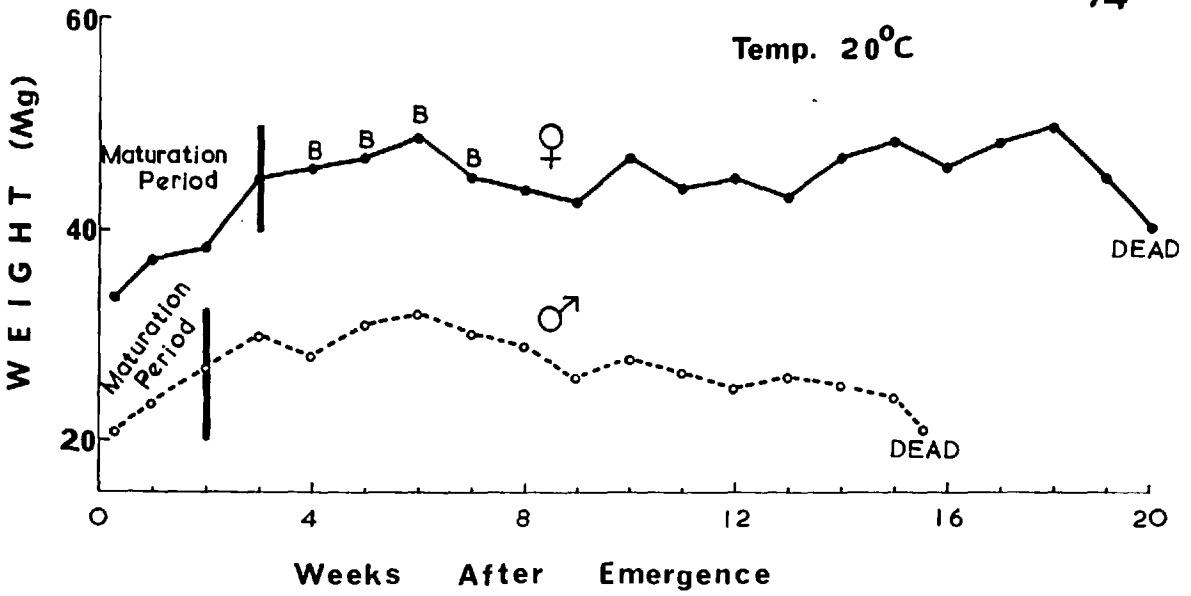
1.0 cm

FIG. 13.– AELIA ACUMINATA L.

England with an obligatory diapause which is terminated during aestivation and part of the hibernation period in early Winter. In the field, the adults of the new generation appear in August and September. These bugs fail to mature when they are put into breeding cages at 25 - 30°C in the laboratory. Aelia reared from egg to adult on dry grain of wheat with water at 25 - 28°C, were unable to mature sexually. The feature of adult diapause in A. acuminata was the arrest of the development of the reproductive organs for at least two months, after the appearance of the adults. Voegelé (1961) reports that among the population of the Moroccan species of Aelia some individuals which were reared at 30 - 31°C were able to breed without diapause. By October at Silwood the newly emerged adults were found to mature sexually but their fecundity appeared to be very low. Preliminary experiments indicated that sexual maturation in this species is determined by low temperature and the changes in photoperiodism which are the important factors regulating the arrest of maturation during diapause.

b) Changes in the Weight of the Adult

Both sexes of Aelia bred in the laboratory were weighed throughout their lives at three-day intervals from their emergence to hibernation and death. At 25°C the maturation period in most males lasted about five days and that in the



B = Batch of Eggs

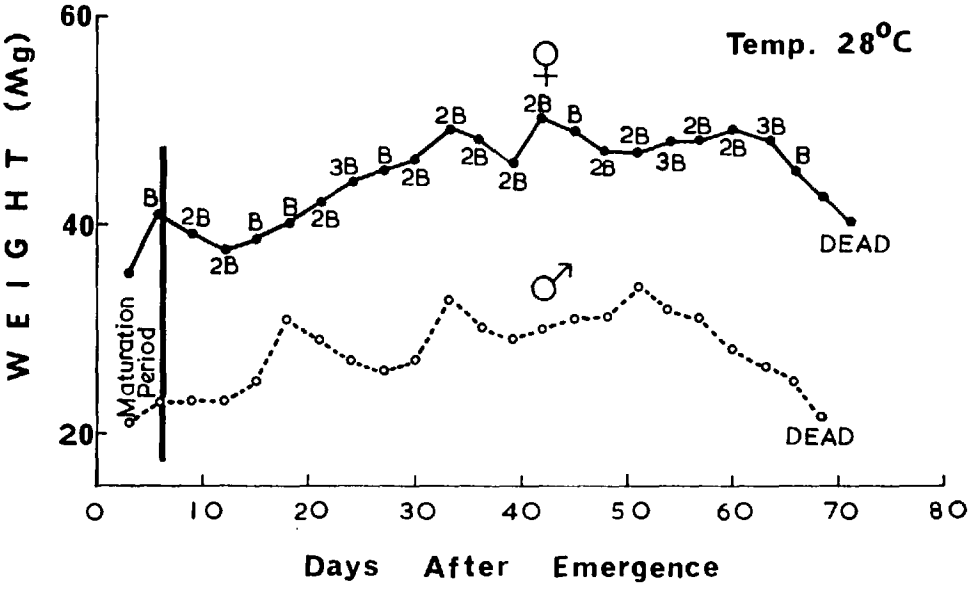


Fig.14.— Changes in Weight of a Male and Female of A. acuminata throughout their Active Life at Low and High Temperature

females a week. This period was shorter at 28°C and longer at 20°C. During this period, however, there was a gradual increase in weight in both sexes which then fluctuated every two to three days. Figure 14 depicts the weight changes of an individual male and a female of A. acuminata at 20 and 28°C throughout the active lives of these bugs.

c) Changes in the Reproductive Organs on Maturation

In the males the changes are the development of the testis and of the seminal vesicles, as well as in the accessary glands which become swollen and well differentiated.

In the females the changes are more marked than in the males. The fat body is small and dirty-yellow but it soon increases in size and becomes brighter; the spermatheca becomes swollen, ovarioles gradually develop and produce eggs which fill up the abdomen (fig. 13).

The development of ovarioles was studied by regular dissections of 4 - 5 females collected in the field every three days, from the beginning of May to October in 1965. Dissections were also made of the females which were bred in the laboratory. From these observations the changes in ovarial development were studied. These changes can be summarised in the following stages:-

Ist stage: Immature ovarioles

Ovary and oviducts thin and threadlike.

IInd stage: Beginning of differentiation of oocytes.

Similar to first stage, but the first signs of a

light cream oocyte appears in each ovariole.

IIIrd stage: Development of one egg

One light cream and one barrel-shaped egg is formed and the signs of another oocyte on the top of previous one is also seen. The width of the lateral and the common oviducts are narrower than the middle of ovarioles.

IVth stage: Mature, two eggs well developed

Two light cream eggs are developed in each ovariole; sometimes one egg is seen in the oviduct. Corpora lutea are not visible. The female is ready to oviposit, or it has previously laid eggs once.

Vth stage: Two eggs developed

Similar to previous stage, but the female has laid and corpora lutea are faintly visible.

VIth stage: Post oviposition

Each ovariole has at least one developed egg. Corpora lutea are visible.

VIIth stage: The end of post oviposition

Ovarioles shorter in length and width than in the four previous stages. Corpora lutea distinct. At this stage the female has laid all her full complement of eggs and dies within a few days.

The above classification of the ovarial development is shown in fig. 13 . The period for each stage in the field in southern England in 1965 is diagrammatically depicted in fig. 12.

8. Fecundity in Captivity and in the Field

Results obtained on fecundity are based on oviposition of the overwintered females from the field. A pair of A. acuminata were used in each replicate, both in the field and in the laboratory experiments.

a) Fecundity in the Field

The cages used were cylinders of celluloid of the third design (page 32). The food was in the form of green blades of grasses with ears, mainly Agrostis, Festuca, Poa, Lolium and of Bromus spp.

In Spring 1965, twenty-five pairs of Aelia were bred separately. They were fed on grasses which were growing in North Gravel. The counts of eggs laid were made every three days. Out of the twenty-five females two lived for 54 and 58 days and did not oviposit, for some unknown reason.

The length of the pre-oviposition period was 8.5 days and its limits 6 - 14 days. The mean longevity of the males was 65 days and that of the females 92.5. The detailed data are given in Appendix I. The results are summarised in Table 2.

Table 2. Oviposition of A. acuminata in 1965

No. of females (Replicates)	No. of eggs per female				Distribution of oviposition sites per female		
	No. of batches		No. of eggs				
	Limits	Mean	Limits	Mean	Ears	Leaves	Stems and Muslin
25	1 - 14	6.4	12 - 161	75.7	54.7	17.5	3.5

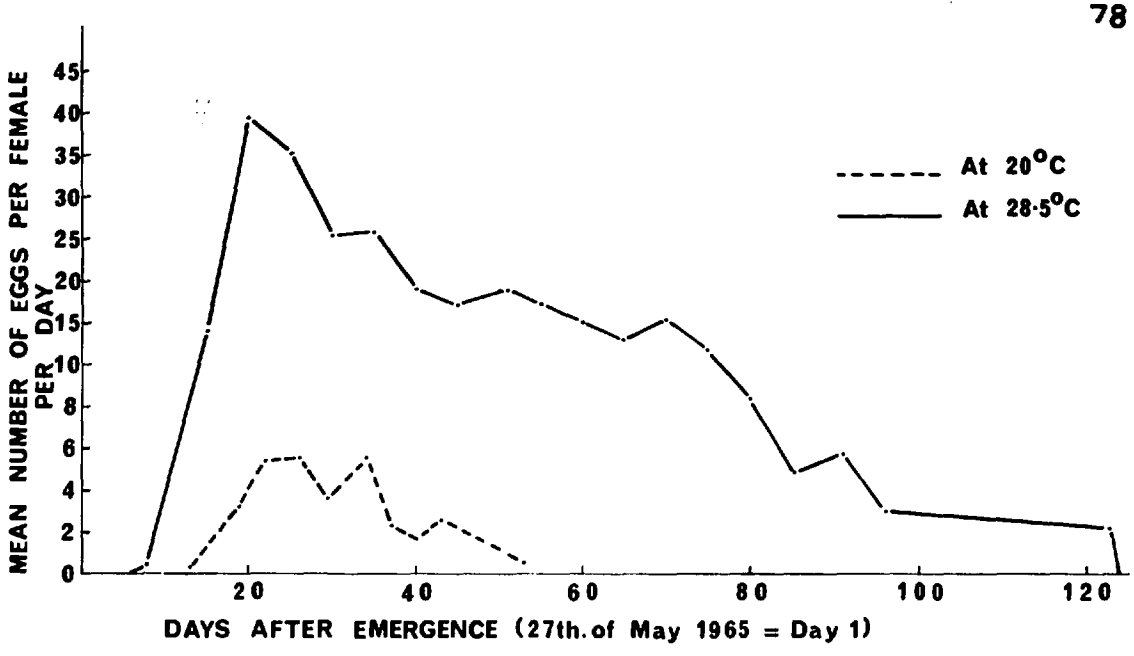


Fig.15.-COMPARISON OF THE FECUNDITY OF Aelia acuminata FED ON WHEAT AND BARLEY GRAIN WITH WATER AT 20 AND 28·5°C

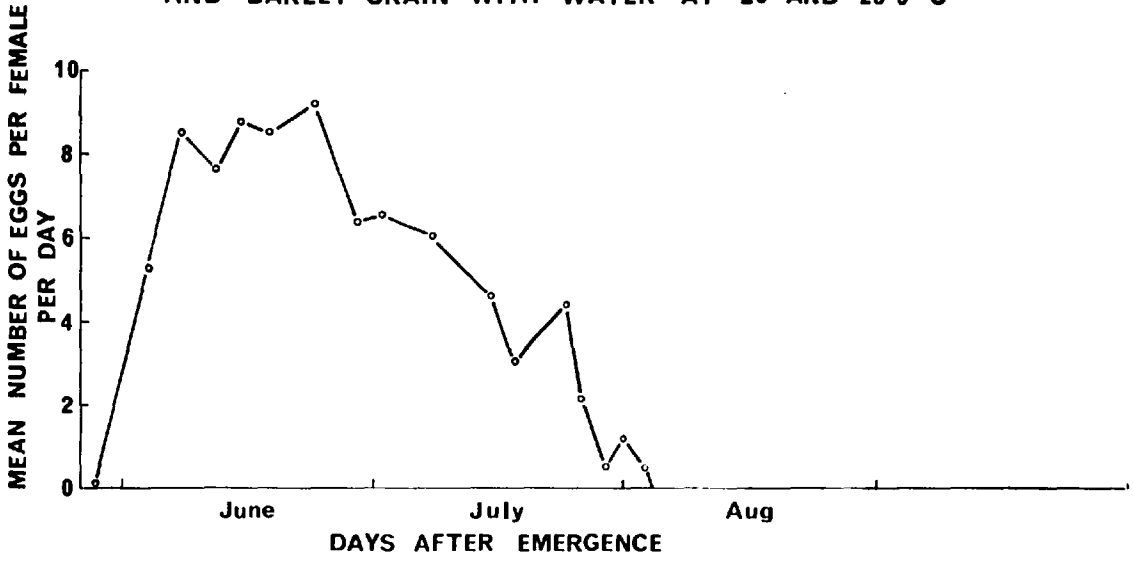


Fig.16.-THE FECUNDITY OF Aelia acuminata FED ON GRASS IN THE FIELD IN 1965

The mean number of eggs per female per week was plotted against time and is shown in fig. 16 . The highest number of eggs was laid during June and the peak of oviposition was on about the 23rd of this month. Later, there is a sharp decline towards the end of June which continues to the early days of August, when oviposition ceases. A comparison of the oviposition curve with that of the air and soil temperatures (fig. 12) clearly indicates the effect of higher temperatures.

With several exceptions, fecundity was also positively related to longevity. The eggs were mostly laid in batches of 12 attached by their sides and in two rows, each of six eggs. This, however, varied occasionally among some individuals and the number of eggs ranged from 5 to 15 per batch.

The oviposition sites of the females were also studied and are shown in Appendix I and Table 2. The results indicate that out of an average of 75.7 eggs per female, 54.7 eggs were laid on the ears (mostly of Festuca and Agrostis) of grasses, whereas 17.5 eggs were oviposited on leaves and 3.5 on stems and muslin. Thus, it seems that the females prefer to lay on the ears of grasses in the field.

b) Fecundity in Captivity

The cages used were polystyrene boxes of the second design (page 43). The food was wheat and barley grain with water (see page 39). In this way fecundity of Aelia was investigated at 20 and 28.5°C. This was especially interesting

as A. acuminata is known to be a pest of cereals in warm climates.

Throughout the experiments both sexes were weighed every three days. The changes in weight of a pair taken at random for both 20° and 28.5°C are shown in fig. 14 . Besides the fecundity and weight, the longevity and the oviposition sites of the females were also studied. The details of the data of these experiments are given in Appendix II and III. The results can be summarised in Table 3.

Table 3. Oviposition of A. acuminata at 20° and 28.5°C

No. of females (replicates)	Temperature °C	No. of eggs per female				Distribution of oviposition sites per female		
		No. of batches		No. of eggs				
		Limits	Mean	Limits	Mean	Cardboard	Muslin	Glass and Plastic
20	20	1 - 6	2.5	5 - 71	30.3	10.4	15.3	4.6
20	28.5	3 - 53	24.7	36-623	291.3	8.4	197.1	85.8

When the mean number of eggs per female per five days is plotted against time for the whole period of oviposition a marked difference is seen between the rate of egg laying at the low and high temperatures (fig. 15). This difference can also be seen in fig. 16 . At 20°C the average longevity of 20 males was 113.7 days and 215.2 in the females; this average dropped to 51.2 days in the males and 61.6 days in the females at 28.5°C.

At both temperatures the females laid most of their eggs under muslin sheets covering the floor of the cage. In both

series of experiments the counts of eggs were made at least once a day.

A comparison of the number of eggs laid per females in the field (average of 75.7) with that at constant temperatures of 20°C (30.3 eggs) and 28.5°C (291.3 eggs) in the laboratory obviously indicate that temperature has a great influence on fecundity of Aelia. Therefore, it is not surprising that this pentatomid is a pest in regions with higher temperatures than in southern England.

9. Rearing of Aelia

In 1965 in the field the complete development of Aelia from egg to adult was 79 days in rearing cages on North Gravel when they were provided with ears of grasses. All the nymphs which were reared on leaves and stems of these grasses failed to develop beyond the fourth stage. It appears that the ears of the host plant are essential for the growth of Aelia.

In the laboratory Aelia was reared successfully on wheat and barley grain with water at 25°C and 28°C. The length of development at 28°C was 29 - 31 days.

10. Aggregation

The nymphs of all stages and the adults aggregate in the field and in the laboratory. These aggregates are more frequent and numerous in early stages in the field and in adults of new generations in aestivation sites.

11. Migration, Aestivation and Hibernation

Towards the end of August and in September Aelia were seen to migrate from the breeding areas at Silwood and at Yateley, to the nearby trees at a radius of not more than 100 m. Those adults which developed later, at the end of September and in early October, were seen to fly to the nearest trees during the warmer sunny days. By the middle of October no Aelia were found in their breeding areas. The bugs overwintered in the southern margin of woodland under grasses from November to the end of the next April and May.

12. The Sex Ratio

The ratio of males to females in the offspring of Aelia was 1 : 1. In the overwintered adults there were more females than males. In 1965 out of 128 Aelia collected at Silwood in three days in June and in July, 51 were males and 77 females; at Yateley out of 31 Aelia collected on 4th June, 13 were males and 18 were females. Thus the sex ratio of overwintered Aelia was 1 male : 1.5 females.

Eurygaster integriceps Puton

This scutellerid, known as "Sunn Pest" or "Senn" is a serious pest of wheat, and, to a lesser extent, barley cultivations in South-West Asia and particularly in the Middle East countries.

A great deal of research has been done on the biology of this pentatomoid. E. integriceps is well known for its migratory habits, as well as for a defined annual cycle of changes in the physiological state in adult life.

Most of the basic research on Eurygaster has been done in the U.S.S.R. There are four important volumes edited by Fedotov (1947 - 60). Further references in Russian are given by Puchkov in the two volumes on Pentatomoidea (1961, 1965). An abstract of the references on E. integriceps can be found in an unpublished report by A.S.Balachowsky (1956) which was prepared for the Food and Agriculture Organisation (FAO).

As regards the research on the biology of this pest in other countries, more attention has been paid to the study of E. integriceps in Iran and Turkey in years of "outbreaks." In Iran "Senn" causes an important reduction of wheat crops. It is also economically important in several other countries of the Middle East, where wheat and barley are the main cultivations and the greatest source of food.

The losses of food crops in these countries caused by the attacks of E. integriceps was so great that FAO has recently organised a long-term research programme on this problem. From this

organisation a series of about 15 unpublished reports on the biology of Eurygaster and its control in Iran have been written by H.E.Martin et al. (1960 - 64), as well as several memoirs by G. Remaudière et al. in the Middle East. A three years research study was also organised on this problem by the Central Treaty Organisation (CENTO) which was carried out from 1958 - 60 by E.S.Brown and by C.J.Banks and their colleagues in Iran and Turkey and a number of papers (about 10) have been published by them in which the ecology and biology of this pest are discussed.

The aim of the present study on E. integriceps was to carry out some investigations of the reproductive biology with special reference to fecundity (on different food and in different temperatures), diapause, and the relationship of these factors to the migration of this pest. This was an ambitious programme and impossible to carry out, partly because of the work on the other Pentatomoidea and their parasites, and also because E. integriceps does not occur in Britain. The necessity for such research, however, was supported by the Plant Pests Research Institute in Tehran and the supply of Eurygaster was offered by this Institute regularly for this study. The insects have been collected during their hibernation period in 1964 and 1965 from Gharah-Aghadg and Jusedan mountains in Iran and have been kept at low temperature (1 - 3°C) during transit to England and at the Imperial College Field Station before their use. In all experiments only those Eurygaster which were judged to be in a healthy condition have been used.

1. Life History:

Eurygaster integriceps is a univoltine pentatomoid having an obligate diapause throughout its range of geographical distribution (Zwölfer, 1930, 1932; Fedotov, 1947 - 60; Martin et al., 1960 - 64; Brown, 1962 - 66).

The insect lives for one year, and its life can be divided into two active and a passive period. The length of the active period is about two and a half to three months which is spent on graminaceous plants in the field. During this period, feeding, mating, oviposition and development of immature stages takes place; the overwintered adults die and the adults of the new generation appear. The adults and their nymphs are active in high temperature and feed intensively on stems, leaves and particularly on ears of their hosts. The attacked plant dies and the production of crops is reduced. At the end of this period the young adults migrate to high altitudes in the mountain areas far from the breeding field for aestivation at lower temperature. The passive period then starts from mid summer and ends early the next spring. The length of this period, therefore, is about nine months and is known as the aestivation and hibernation period. During the hot and dry months of the late summer and autumn, Eurygaster aestivate within or under plants at high altitudes, and before the cool weather sets in, migrate to lower altitudes where the bugs hibernate, mostly on the southern slopes under plants and dead leaves for the rest of the autumn and the winter months. The insects spend the passive period as adults and are almost completely inactive during the cold weather.

In early spring, when the temperature rises to about 18°C, E. integriceps leave their hibernation sites and migrate to the field, when they repeat their annual generation.

2. Reproductive Biology.

a) Reproductive Organs:

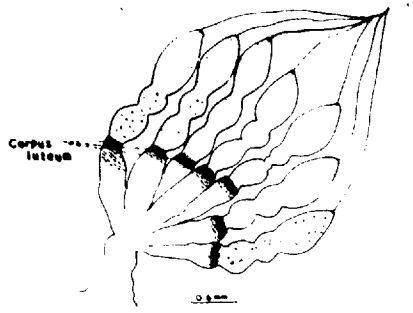
The morphology of the female and male reproductive systems are shown in fig. 17. The female has a pair of ovaries each consisting of seven ovarioles. In the male there are a pair of orange testes with five accessory glands. The detailed description of these organs can be found in Fedotov (1947), Vodjdani (1954).

3. Sexual Maturation:

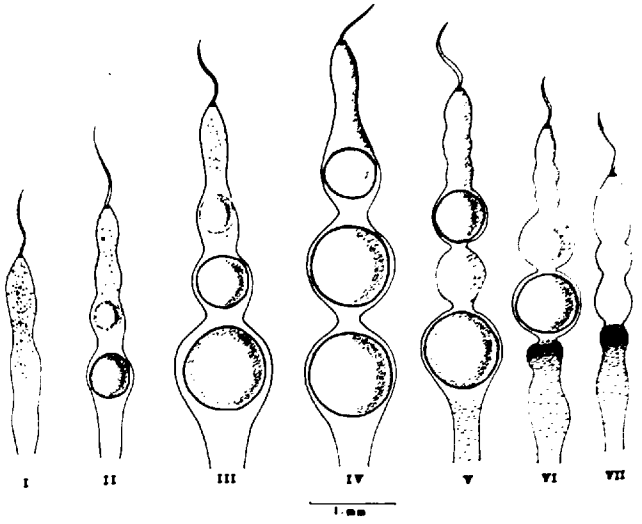
The new generation of E. integriceps mature sexually after the termination of diapause in early winter. This includes aestivation and part hibernation. During this period, physiological changes occur, and the fat-body and the weight of the insect gradually decrease and reach their minimum, after Eurygaster descends to the fields in spring (Fedotov 1947 - 60; Brown, 1962). During the aestivation period the insect is partially mobile, whereas during the hibernation period the population is almost completely inactive and the bugs are in a state of diapause.

a) Diapause:

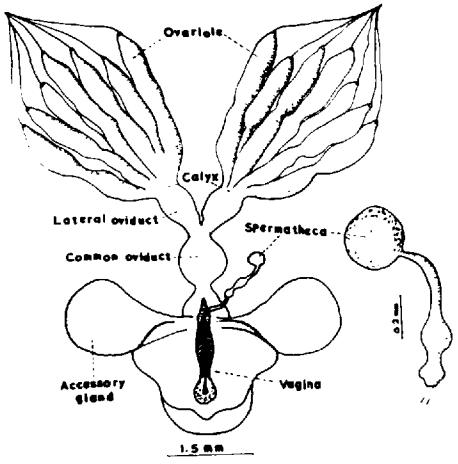
The duration of diapause is about six months in the annual life cycle of each generation, starting from the hot and dry months of summer and ending in winter. The diapause is characterised by an arrest of development of the reproductive organs.



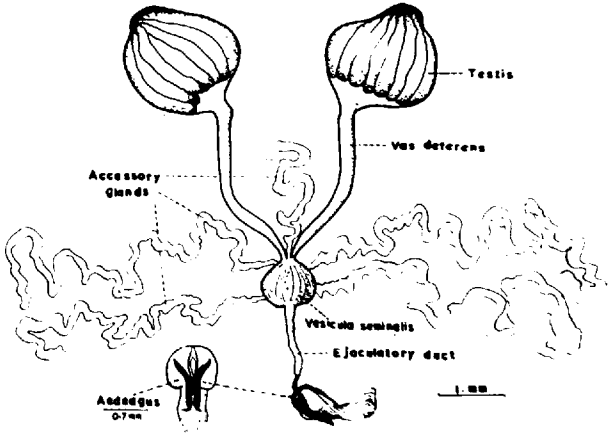
RIGHT OVARY IN POST OVIPOSITION



DIFFERENT STAGES OF OVARIAL DEVELOPMENT



FEMALE REPRODUCTIVE ORGANS AT MATURATION



MALE REPRODUCTIVE ORGANS

FIG.17.- **EURYGASTER INTEGRICEPS** PUTON

Up to now, all attempts to break diapause in E. integriceps have failed. Most of the knowledge on this subject has been derived from observation on the general biology of the insect. There is, however, very little published experimental work on the diapause of Eurygaster; in spite of the extensive literature on the physiological changes of this pentatomoid during the passive stage of its life. Thus, it was intended to study this problem in relation to photoperiodism and temperature, since these factors are known to control diapause in many other insects (see Andrewartha, 1952; Lees, 1955; Danilevskii, 1965).

In nature E. integriceps has become very adaptive to unfavourable climatical conditions and especially to the change of temperature ranging from - 21 to 42°C. The effects of temperature and photoperiodism on the diapause of this pest have been studied using E. integriceps which were bred and developed to adult stage in the laboratory at 28.5°C under a photoperiod of 16 hours and fed on wheat grain and water. For convenience these have been named as "Laboratory Eurygaster" and are discussed as group A. Those Eurygaster received from Iran have been called "Field Eurygaster" and are discussed as group B.

G R O U P A.

Experiments on Diapausing "Laboratory" *E. integriceps*

Group A1

Laboratory bred Eurygaster

Exp. No.	No. Replicates	Experimental conditions	Examination	Results
No. 1 (15.3.64 - 24.4.65)	(a) 10 pairs	28.5°C; 60V light, 16 hour photoperiod. Cages design No. 1. Food wheat and barley grain and water.	Every 2nd day; food changed weekly.	Bugs fed for 3 weeks, then rested. 50% died by Feb. 1965; by then only 5 ♀♀, 3 ♂♂ alive.
	5 pairs	As above, but larger cages of design No. 3.		
	(b) 3♀♀ 2♂♂ survivors of (a) in February	Transferred to diet of growing wheat shoots	Food changed every 3 days	All died in 35 days. No copulation; remained immature; fat bodies small, dirty-yellow (pale yellow on emergence)
No. 2 15.3.64	(a) As above 15 pairs	As (a) above but at 20°C	As (a) above.	Longevity 2 - 8 months; after 6 months only 9♀♀, 5 ♂♂ alive; remained immature; fed only rarely.
	(b) After 6 months 3 pairs	Transferred to diet of growing wheat shoots at 28°C.		Showed increased activity; ♀♀ lived 18 - 32 days, ♂♂ 5 - 26; remained immature; no copulation.

Group A1 (Cont.)

Exp. No.	No. Replicates	Experimental conditions	Examination	Results
No.3 July 1965 - Feb. 1966	(a) 15 pairs	As exp. 2(a) at 20°C but photoperiod gradually decreasing by 1 hr per 22 - 25 days from 17 hrs to 7 hrs.		Mortality 48% after 6 months; remained immature.
	(b) 6 pairs survivors of (a) in Feb. 1966	Transferred to 28.5°C into cages growing wheat shoots.		Fed on wheat; lived 16 - 39 days. Dissections after death showed that in 2♀♀ oocytes began differentiating; fat body remained small and dirty-yellow.
No. 4 15.3.64	20 pairs	10 pairs kept at 20°C and 10 pairs at 28.5°C, 16 hr photoperiod. Food wheat grain and water. Each laboratory ♀ was provided with overwintered field ♂ and vice versa.		All field ♂♂ and ♀♀ active and showed pre-mating behaviour. All laboratory insects remained inactive and immature. Field bugs lived 18 - 67 days at 28.5°C and 24 - 151 at 20°C. Laboratory bugs lived over eight months at 28.5°C and 20°C. At 28.5°C 3 field ♀♀ laid 2 - 4 egg batches, but all 55 eggs were unfertilised and failed to hatch. Thus "field" males and females failed to stimulate maturation in the "laboratory" ones.

Group A2

(Effect of Changing Photoperiod)

Laboratory bred *Eurygaster* which on 26th March 1964 were transferred to the field conditions i.e. to outdoor temperatures and outdoor changing photoperiod.

Exp. No.	No. Replicates	Experimental conditions	Examination	Results
No. 5	(125 pairs)			
	Set 1. 10 pairs	(i) Returned May 1964 to 28.5°C, fed on wheat grain and water.	Every 2nd day; food changed every 3 days.	Lived 13 - 78 days; remained immature; no copulation.
	Set 2. 10 pairs	(ii) Returned end of July 1964 to 28.5°C, fed on wheat grain	-	Life 21 - 123 days; no copulation or oviposition but 2 ♀♀ dissected on 17th February had developing green eggs in one ovary.
	Set 3. 43 females 29 males	Transferred to 10°C 75% R.H. (No feeding at this t°) at end of Sept. - Dec. Then 5 pairs transferred to 28.5°C; given wheat grain and water.	-	Life 2 - 3 months; no copulation or oviposition; 3 females dissected on death had 1 - 2 developing green eggs.

Group A2 (Cont.)

Exp. No	No. Replicates	Experimental conditions	Examination	Results
	Set 4.	In mid Feb. Another 5 pairs from 10°C transferred to 28.5°C		
		(i) given wheat grain with water.	-	No copulation or oviposition
		(ii) end of Feb. 4 remaining pairs given wheat shoots	-	Fed repeatedly on green shoots; copulated by first week in March; matured and oviposited.

Group A3

Laboratory bred Eurygaster, put at 1 - 2°C, 75 - 78% R.H.

in May 1965. (50% died at 1 - 2°C by December

Exp. No.	No. Replicates	Experimental conditions	Examination	Results
No. 6	56 pairs	5 pairs at a time placed at 28.5°C, 16 hr photoperiod in August, September, November and January.	Every 2nd day, food as above	Life 5 - 56 days; none copulated or matured; mid-intestine with food.

GROUP B.
Diapause in "Field" E. integriceps

The results of a series of experiments carried out in relation to diapause by using adult Eurygaster from Iran can be summarised as follows:- The insects were bred at 20 and 28.5°C constant temperature at a 16 hour photoperiod, as in experiments No. 1 and No. 2 of group A.

1) All E. integriceps of the new generation, collected in the field and in mountains during July and August, failed to mature in captivity. On dissection it was seen that the reproductive organs of both sexes were similar to those in experiment No. 1 and No. 2 of group A. The mortality of these insects was 36% and 75% by July and September respectively. The bugs lived 3 - 112 days at 20°C and 1 - 92 days at 28°C. In all replicates at both temperatures neither copulation nor oviposition was observed throughout their lives.

2) E. integriceps which were collected during November to April matured and oviposited at 20°C, 23.5°, 28.5° and 30°C.

3) Females and males which hibernated under grasses in the Heath field at Silwood Park copulated and oviposited on grasses in June 1965. At. 20°C however, several females did not lay, although they mated and had developed eggs in their ovarioles.

Results:

The above data indicate that sexual maturation in E. integriceps is influenced by both changes in photoperiod and temperature.

Conclusions:

The following conclusions can be drawn from the above experiments:-

1) There is an obligate diapause in each generation of E. integriceps (both in those reared in the field and in the laboratory).

2) Young Eurygaster diapause both at high and at low temperatures.

3) Preliminary experiments indicate that diapause in E. integriceps is influenced by both photoperiodism and temperature.

4) Food in the form of green wheat shoots stimulated sexual maturation and oviposition in E. integriceps.

5) The data support the hypothesis of sexual maturation of "Sunn Pest" without migration (Aronl'di, 1955; Martin et al., 1961 - 63; Safavi, 1961).

6) The number of eggs in females that had not migrated was lower than in the migrated individuals collected during winter in their hibernation site in Iran in 1964 and 1965 (see section on fecundity).

b) Changes in Weight of the Females.

All females of E. integriceps bred in the laboratory were weighed throughout their lives at three-day intervals. Figures 19 and 21 depict the weight changes of three of the females in different conditions of temperature and food. At 28.5°C the maturation period in most females and males lasted about seven days, This period was about nine days at 23.5°C and up to 30 days at 20°C. In the preoviposition period the females increased in weight which then fluctuated every two to six days, this being correlated with feeding, oviposition and temperature. The fluctuations were more marked at 28.5°C.

c) Changes in the Reproductive Organs on Maturation.

Fedotov (1947) has given a summary of the changes in the reproductive organs of E. integriceps. Also Brown (1962); Martin

et al. (1960 - 63) write on this topic. I have examined these changes both in Eurygaster from Iran, and in the bugs reared to adult stage on wheat at 28.5°C. Some preliminary experiments were also carried out on diapause of this insect to see its effect on sexual maturation.

In both series the changes in reproductive organs on maturation were distinct. In the males the testis changed from being shortly-fanlike and faintly yellow-coloured to being pear-shaped and brownish-red on maturation; the accessory glands became swollen and the seminal vesicles thick.

In the females the changes are marked by formation of green eggs in the ovarioles which fill most of the haemocoele; the spermatheca becomes swollen; the fat body is small and dirty greyish. The females were dissected and examined at intervals. The changes in the ovarioles are depicted in fig. 17. They can be summarised as follows:-

Ist Stage: Immature Ovarioles.

Ovary and oviducts thin and threadlike.

IInd Stage: Beginning of Differentiation of Oocytes.

Similar to the first stage, but the first faintly-green oocyte appears in each ovariole.

IIIrd Stage: Development of One Egg.

One round green egg is formed and the signs of another faintly-green oocyte above the previous one is also seen. The width of the lateral and the common oviducts are narrower than the

middle of the ovarioles.

IVth Stage: Mature, Two Eggs well Developed.

Two round green eggs are developed in each ovariole. Signs of a light green oocyte are also seen above these eggs. Occasionally one of the two mature eggs can be seen in the lateral, or in the common oviduct. The female is ready to oviposit, or she may have laid once. Corpora lutea are not visible.

Vth Stage: One Mature Egg.

At least one well developed green egg is seen in each ovariole, or sometimes two as in stage IV. A faintly-green oocyte is also seen below the germarium. One egg may also be seen in the lateral, or in the common oviducts. Corpora lutea are faintly visible. The females usually lay most of their eggs at this stage.

VIth Stage: Post Oviposition Period.

A small green egg is seen in each ovariole. Corpora lutea are clearly visible.

VIIth Stage: The end of Post Oviposition Period.

All ovarioles are without eggs or oocytes. Corpora lutea distinct. At this stage the female has laid all her eggs and dies within a few days.

4. Copulation in Eurygaster integriceps Puton

The description of genital segment of E. integriceps is given by Puton (1881), Vodjdani (1954), Wagner (1959), Puchkov (1961) and Brown (1962).

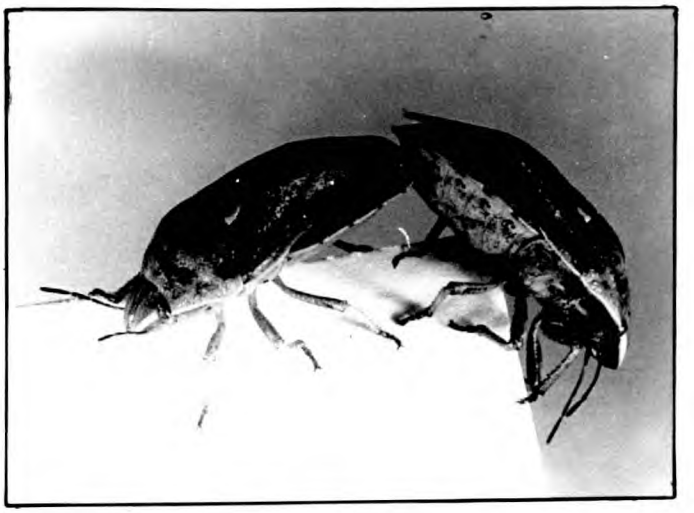


Fig. 17a. A pair of Eurygaster integriceps in copulation (female on the right)

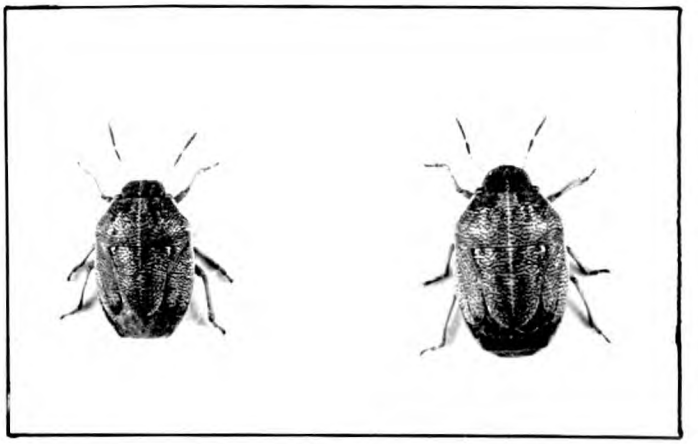
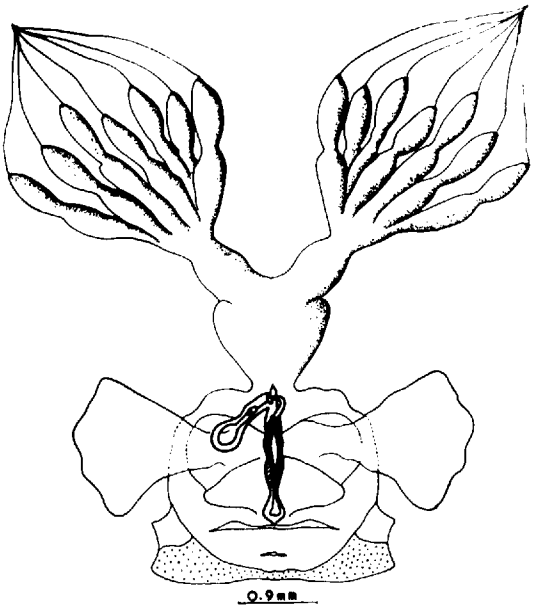


Fig. 17b. A pair of Neottiglossa pusilla (female on the right)

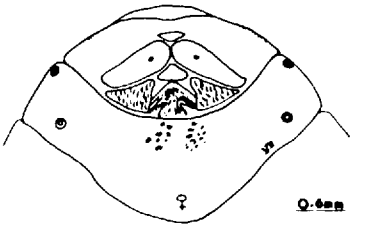
Mating behaviour of this pest has also been mentioned by several Russian authors (Alexendrow, 1947 - 49; Makhotine, 1947). In these references the description of aedeagus and its appendages was based on live, or dead material (after maceration of dead specimens). The function of the different parts of external genitalia have not been previously studied, however. The pair readily part on disturbance and this may be the reason for this.

Normally the aedeagus is withdrawn within the 9th segment and the vesica and conjunctival appendages lie collapsed within the theca; thus, in order to show the function of these segments they must be figured when extended during natural mating (Leston, 1955). In the present study this was done by dissecting 11 pairs of copulating E. integriceps after plunging them into boiling water. In this way the pairs died while copulating, and no abnormal contraction or expansion took place. The pairs were then disconnected by dissection without collapse of the appendages fig. 17a and 18.

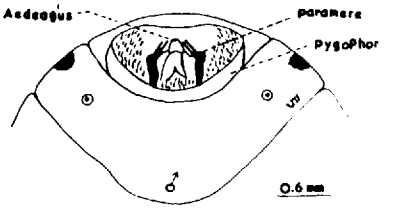
Copulation took place commonly in the breeding cages at temperatures ranging between 19 and 30°C. The pre-mating behaviour was well marked by the male stridulation close to the sides of the female. This movement took place between 2 and 18 minutes at various temperatures and in different individuals. The males also touched the females by their antennae and rarely mounted them while continuing the movement of the last abdominal segment up and down. Unmated females before oviposition, and



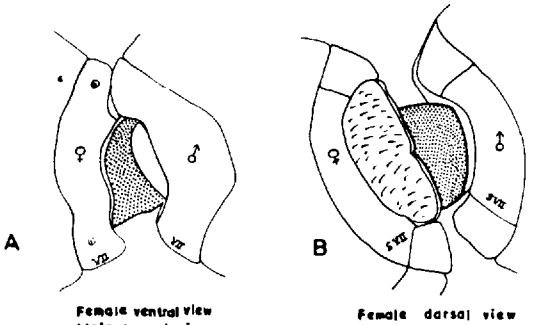
REPRODUCTIVE ORGANS OF FEMALE OF 'LABORATORY BRED' E. integriceps AFTER 13 MONTHS AT 28°C AND AT A 16 HOUR DAILY PHOTOPERIOD. NOTE: OVARIOLES AND SPERMATHECA HAVE NOT DEVELOPED AT ALL.

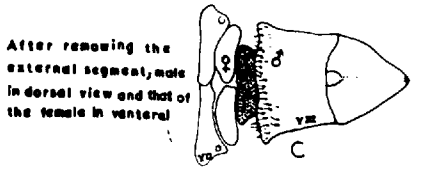


OVIPOSITOR AND VENTRAL ASPECT OF FEMALE GENITAL SEGMENTS OF E. integriceps SHOWING THE POSITION OF VALVIFERS IN COPULATION.

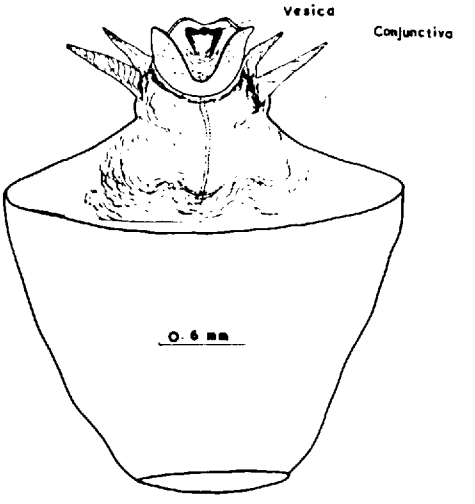


VENTRAL ASPECT OF MALE GENITAL SEGMENTS OF E. integriceps SHOWING PYGOPHORE AND THE POSITION OF APEX OF AEDEAGUS AND PARAMERES IN COPULATION





A, B, C, GENITAL SEGMENT OF A PAIR IN COPULATION



VENTRAL ASPECT OF 9TH SEGMENT OF EXPANDED GENITALIA SHOWING THE POSITION OF THE CONJUNCTIVA DURING FUNCTION IN COPULATION

FIG.18-EURYGASTER INTEGRICEPS

those after ovipositing several batches of eggs respond to the males after about 2 - 6 minutes at 28.5°C.

During all pre-mating stridulation the males extruded their entire 9th segment and rotated the whole genital capsule on both sides some 180°. This was possible because of the intersegmental membrane of the 8th and 9th segment. Connections of the sexes however, were obtained by the males butting the sides (mostly from the right) of the female abdomen and approaching the tip of the aedeagus to the slightly opened valifers of the vagina. These opened by a dorsal shift of the 8th and of the following segments (see fig. 18). The conjunctival appendages of male Eurygaster (fig. 18) lie within the vagina during the whole period of copulation and completely block the external opening of the vagina (fig. 18). The dorsal appendages lie behind the 2nd valvifers which press them against the male gonopods. The vesica enters very closely to the opening of the spermathecal duct; this was easier to see in the dead pair in copulation after treatment for 7 - 8 months in diaphanol, and dissolving away the colour of the external sclerites. The duration of copulation ranged from 2 - 39 hours, and was repeated between 1 - 7 times throughout the lives of the males and females. The males, however, copulated more frequently than the females. During copulation, and particularly before and after this process, the pairs were usually seen feeding, but they tend to remain motionless while copulating.

Mating behaviour in other Pentatomoidea both in the phytophagous and carnivorous species studied was similar to that described in E. integriceps.

5. Fecundity of E. integriceps in Relation to Food and Temperature in the Laboratory.

Much data are available on the fecundity of this insect. Before 1960, the data are mostly based on the fecundity of Eurygaster bred on wheat shoots. Peredel'skii(1947) reports that up to 15 oviposition in a single "Senn" has been observed in the laboratory.

Recently, cultures of cereal Pentatomoidea including that of E. integriceps have been established on wheat grain and water (see page 39). Martin et al. (unpublished, 1960 - 64) has studied in detail the fecundity of this species. His data indicate that the maximum number of batches were laid at 30°C. Fecundity was higher in the females collected at the end of their hibernation period in March and April, their mean being 11.5 batches. He also observed that the fecundity decreased to one batch per female when they were bred on a large scale. Furthermore, he found that fecundity was higher in females fed on wheat grain than those bred on wheat shoots. Martin (1964) suggests that further investigations are necessary to elucidate the factors controlling fecundity.

More knowledge of this subject is essential as E. integriceps is a serious pest and its eggs are used in the mass rearing of the scelionid egg parasites used in its biological control.

Thus fecundity was studied in some detail and effects of food and temperature were investigated. Both wheat and barley were given in the form of grain and also as growing shoots. The experimental insects were E. integriceps collected in the overwintering areas in

central regions of Iran during January, February and March of 1964 and 1965. The insects were transported to London in special cardboard cages with ventilation holes and wet cotton wool, and kept at 2 - 3°C before their use. In all experiments counts of egg were made daily.

A) FECUNDITY of E. integriceps on WHEAT

a) Breeding on Wheat Grain and Water at Different Temperatures.

Experiment No.1:-

Eurygaster was bred in polystyrene cages of the second design. There was a pair of insects in each replicate of each experiment. Common British wheat grain was used (see page 43). Breeding was carried out in a constant temperature at 23.5°C and 28.5°C. The females were weighed every three days throughout their lives. The changes in weight of three females taken at random from both 23.5°C and 28.5°C are shown in fig. 19. Besides fecundity and changes in weights of females, longevity of both sexes was also recorded. The details of these data are given in Appendices IV and V. The results are summarised in table 4.

Table 4. Oviposition of E. integriceps fed on wheat grain and water at low and high temperatures.

Pairs No. (Replicates)	Temperature °C	Mean longevity in days		Fecundity per female			
				No. of batches		No. of eggs	
		Male	Female	Limits	Mean	Limits	Mean
5	23.5	28.6	25.6	1 - 8	6	14 - 112	81.4
25	28.5	39.0	50.1	2 - 31	15.6	14 - 338	195.2

In figure No. 20 the mean number of eggs per female per day is plotted against the time for the whole period of oviposition at both temperatures. In the same figure, the mean of total fecundity

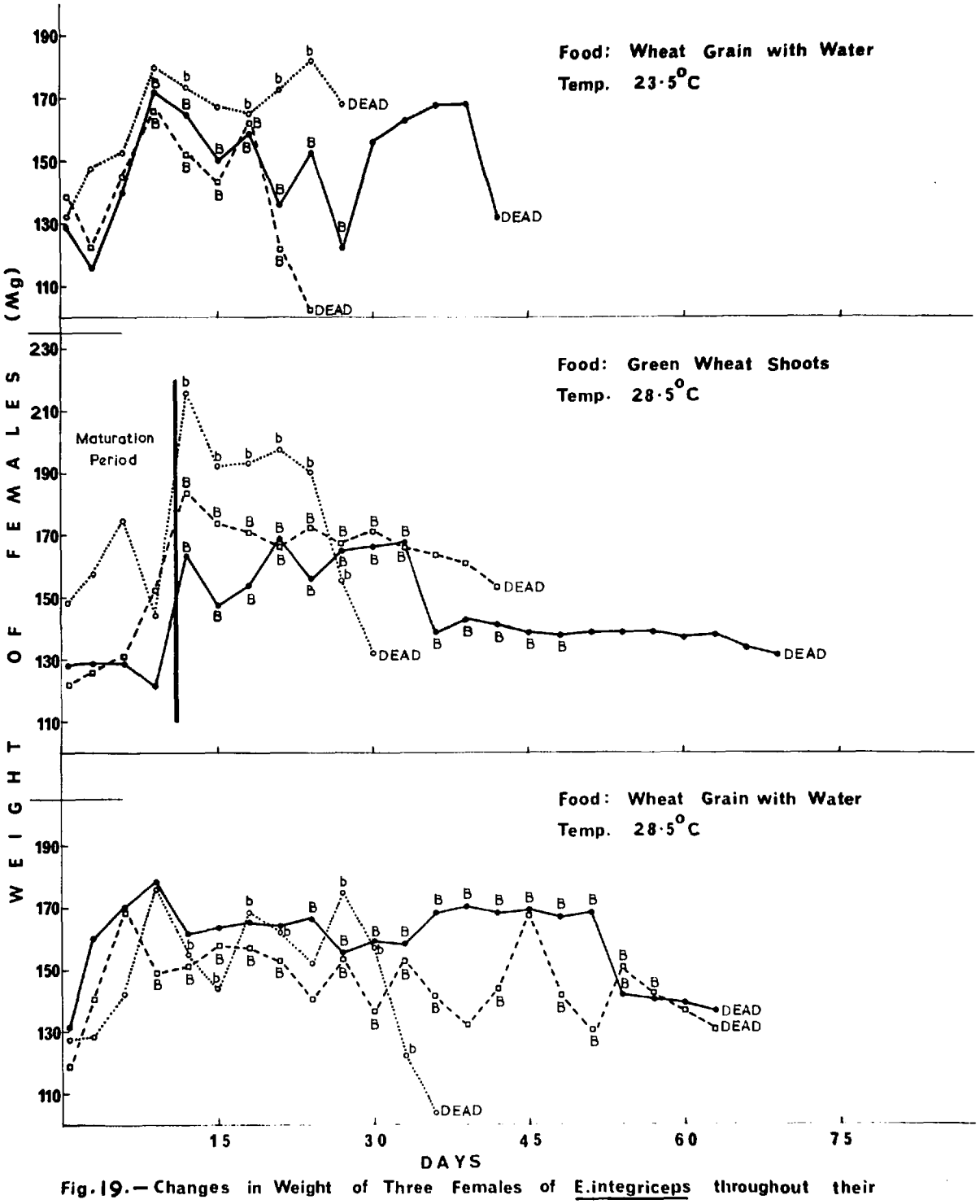


Fig. 19.— Changes in Weight of Three Females of E.integriceps throughout their Active Lives

per female is shown in the form of a histogram. Data in table 4 and figure 20 clearly indicate that fecundity has increased significantly at 28.5°C. It can also be seen that the period of egg laying is much longer at high temperature. For some unknown reason, however, longevity of both sexes unexpectedly decreased at the lower temperature, and the females laid fewer eggs.

At both temperatures the females laid most of their eggs under or on muslin which covered the floor of the cages, and to a smaller extent on the roof-shaped cardboards. At 28.5°C the eggs were mostly laid in batches of 14 in two or three rows and were attached by their sides. However, the number of eggs varied from 3 - 21 per batch. At 23.5°C the number of eggs per batch was more variable, and there was a tendency to lay more than 14 eggs in batches of two rows.

b) Fecundity of Eurygaster fed on wheat shoots.

Experiment No. 2:

The cages used were celluloid cylinders 25 cm in length and 8 cm in diameter with a free end fitted on to the top of the clay pots in which the shoots of wheat were grown (see page 37). In each cage there was a pair of Eurygaster. The experiment was carried out at 28.5°C, the insects were fed on the fresh leaves and stems of the shoots. Throughout the experiment the females were weighed every three days. The changes in weight of three females taken at random are shown in fig. 19. Longevity of both sexes was also recorded. The details of the data of this experiment are given in Appendix VI. The results are summarised in Table 5.

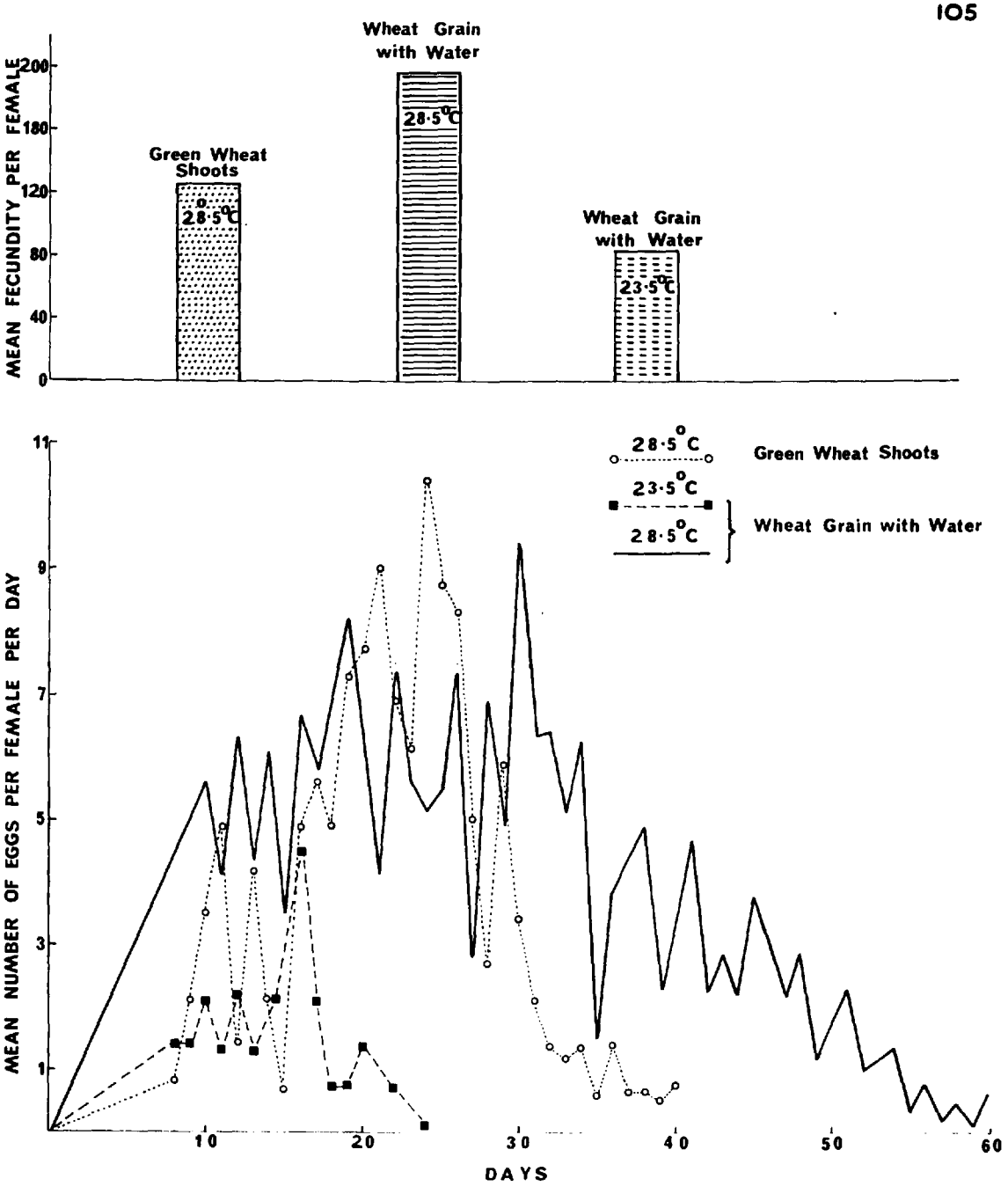


Fig. 20.—FECUNDITY OF Eurygaster integriceps IN RELATION TO FOOD AND TEMPERATURE

Table 5. Oviposition of E. integriceps at 28.5°C; fed on wheat shoots.

Pairs No. (Replicates)	Mean longevity in days		Fecundity per female			
	Male	Female	No. of batches		No. of eggs	
			Limits	Mean	Limits	Mean
25	28.1	33.0	2 - 20	9.1	28 - 267	124

As in the previous experiment, the mean number of eggs per female per day is plotted against the time for the whole oviposition period and this is shown in fig. 20. The mean of total fecundity per female is also shown in histograms in the same figure.

Comparison of Data on Fecundity of E. integriceps bred on Wheat grain and on its Shoots

Both fecundity and longevity on wheat grain and on its shoots are summarised in table 6. It is worth mentioning that Eurygaster used in both experiments at 28.5°C were collected in February 1965 in Iran, and have been cultured simultaneously in the same breeding room at Silwood.

A comparison of data indicate that the fecundity and longevity have significantly increased on wheat grain and water.

Table 6. Fecundity and Longevity of E. integriceps fed on wheat grain, or on its shoots.

Pairs No. (Replicates)	Temperature °C	Food	Mean longevity in days		Mean fecundity per female.	
			Male	Female	No. of batches	Total No. of eggs
25	28.5	wheat shoots	28.1	33.0	9.1	124
25	28.5	wheat grain and water	39.0	50.1	15.6	195.2

Conclusions:

1) The data on fecundity of E. integriceps fed on water and wheat grain, or on its shoots, supports the investigations of Martin et al. (1963-64).

2) Both fecundity and longevity of Eurygaster are significantly higher than those given by Martin and by other authors (see Martin, 1963-64).

3) Fecundity in the present study is based both on the number of batches, and the number of eggs per batch, whereas in Martin's work and that of many others, counts were made only of the number of batches. There is variability in the number of eggs per batch and thus this method provides only an approximation of the pest's fecundity.

B) FECUNDITY of E. integriceps on BARLEY.

In the warmer parts of their area of distribution Aelia and Eurygaster attack barley cultivations. There is no reference in literature to their fecundity either on barley shoots or on the grain. Experiments on fecundity of Eurygaster on these foods were therefore made.

a) Breeding on Barley grain and Water at different Temperatures.

Experiment No.1:

The experients were made in polystyrene cages of the second design and the insects bred on barley grain at 20 and 28.5°C (see page 39 and 43). In each replicate a pair of insects was used. The females were weighed every three days throughout their lives. The changes in weight of three females taken at random are depicted in

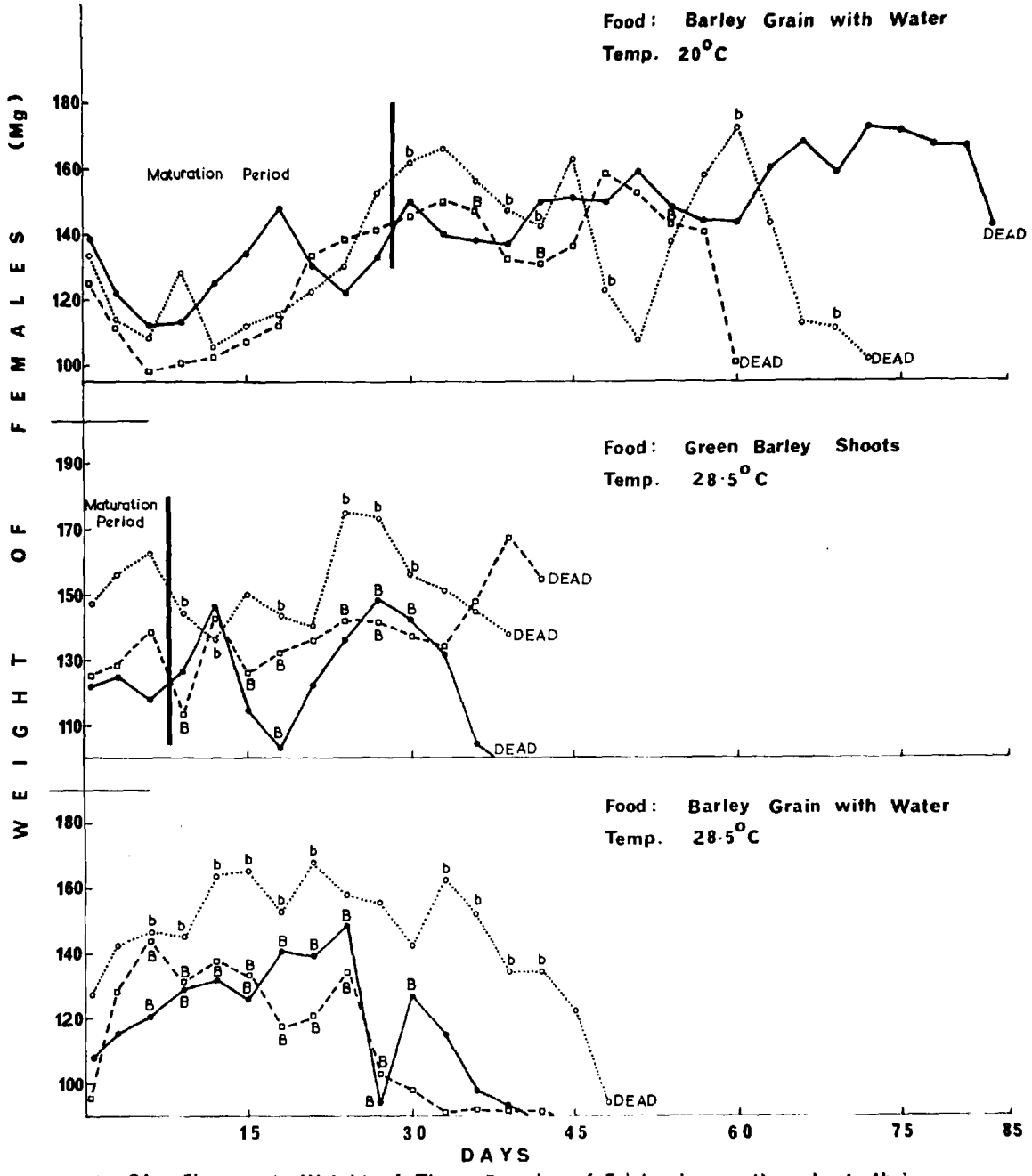


Fig. 21.—Changes in Weight of Three Females of E. integriceps throughout their Active Lives

fig. 21. The longevity of both sexes was also recorded. As in other experiments the eggs were counted at least once a day.

The details of the data of these experiments are given in the Appendices VII and VIII, and the results are summarised in Table 7.

Table 9. Oviposition of E. integriceps fed on barley grain and water in different temperatures.

Pairs No. (Replicates)	Temperature °C	Mean longevity in days		Fecundity per female			
				No. of batches		No. of eggs	
		Male	Female	Limits	Mean	Limits	Mean
20	20	59.0	66.6	1 - 9	2.25	9-117	27
25	28.5	27.2	38.6	1 - 36	14.4	14-377	183

The mean number of eggs per female per day are plotted against time throughout the oviposition period and are shown in figure 22. The mean of total fecundity per female is also depicted as a histogram in the same figure.

A comparison between data obtained indicate that there is a sharp difference between the rate of egg laying at 20 and 28.5°C. Fecundity increased at high temperature and eight of the 20 females did not lay at all at 20°C. As was expected longevity increased at low temperature.

Thus, high temperature has an effect on fecundity of E. integriceps even on barley. It is therefore not surprising that this species can multiply to very large numbers on cereal cultivations in warm climates, as in the fertile valley of Varamin in Iran, or in the south west areas of the U.S.S.R.

b) Fecundity of Eurygaster bred on Barley Shoots.

Experiment No. 2:

The conditions were similar to those when wheat shoots were used. Barley was cultured in cages. Each cage contained a pair of Eurygaster. The experiment was carried out at 28.5°C. The insects were seen to feed on shoots as they did on the wheat shoots. The females were weighed every three days. The changes in weight of three of them taken at random are shown in fig. 21 . The details of the experiment are given in Appendix IX. The results can be summarised in Table 8.

Table 8. Oviposition of E. integriceps fed on barley shoots at 28.5°C

Pairs No. (Replicates)	Mean longevity in days		Fecundity per female			
			No. of batches		No. of eggs	
	Male	Female	Limits	Mean	Limits	Mean
25	30.0	37.7	1 - 17	6.4	2 - 24	83.1

The mean daily number of eggs per female and the mean of the total fecundity per female are both presented as in the previous experiments, and are shown in fig. 22 .

Comparison of Data on Fecundity of E. integriceps bred on Barley grain, or on its Shoots

Both fecundity and longevity of the insect on barley grain and its shoots are summarised in Table 9.

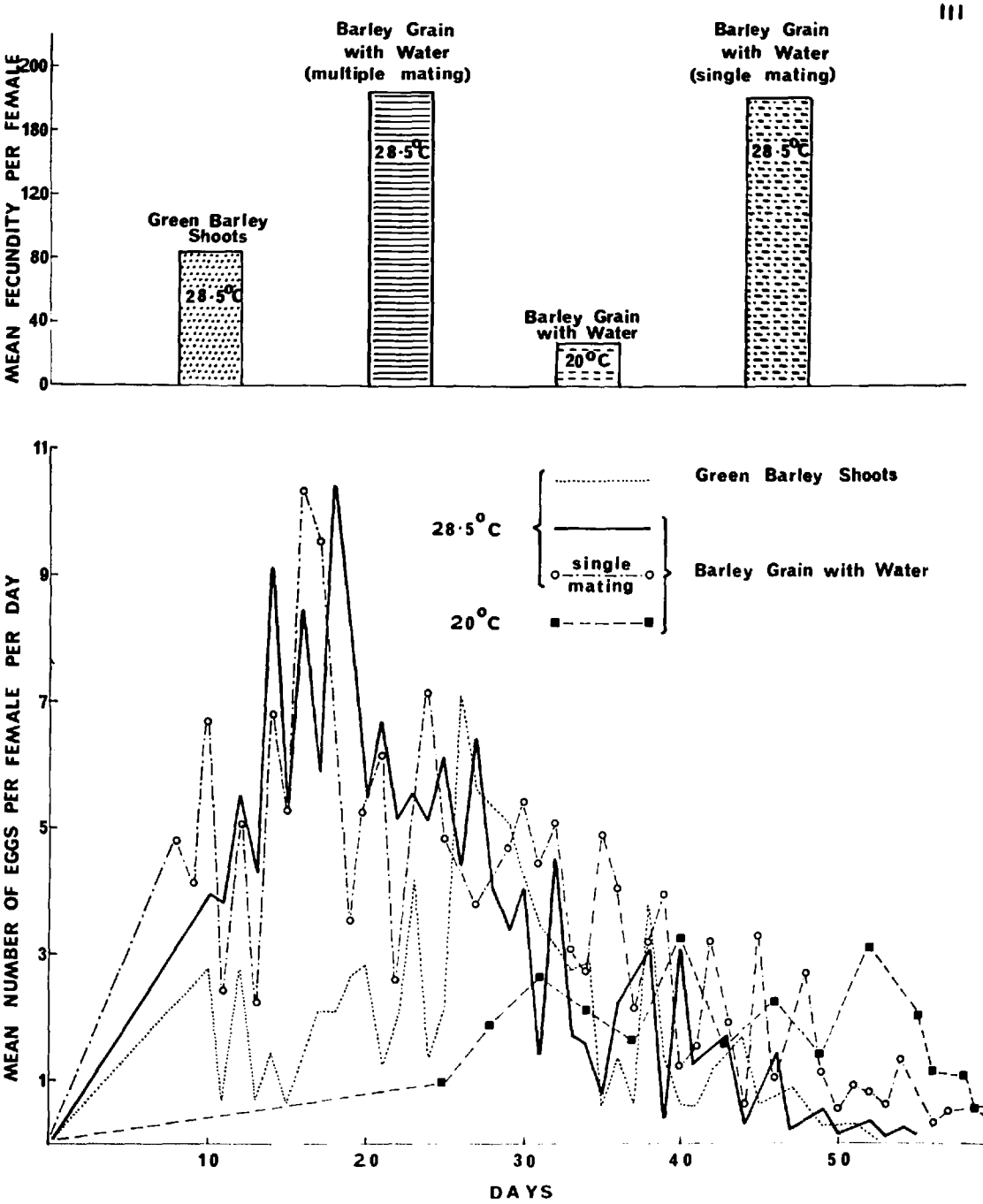


Fig. 22.–FECUNDITY OF Eurygaster integriceps IN RELATION TO FOOD AND TEMPERATURE

Table 9. Fecundity and Longevity of E. integriceps fed on Barley grain, or on its Shoots.

Pairs No. (Replicates)	Temperature °C	Food	Mean Longevity in days		Mean fecundity per female	
			Male	Female	No. of batches	Total No. of eggs
25	28.5	barley shoots	30.0	37.2	6.4	83.1
25	28.5	barley grain and water	27.2	38.6	14.4	183.0

A comparison of the data indicates that the fecundity of this species on barley grain is more than twice that on barley shoots. Longevity, particularly that in the female, is similar on the two foods.

Conclusions:

The following is a comparison of fecundity of E. integriceps on wheat and on barley:-

1 - Fecundity and longevity of E. integriceps are greater on wheat than on barley (both on grains and on shoots).

2 - On both barley and wheat fecundity increased to a high level when the insects were provided with grain and water instead of shoots.

3 - The data confirm that, in the invasion areas of E. integriceps, damage would undoubtedly be much greater to wheat cultivations than to those of barley.

C) The Effect of a Single Copulation on Fecundity of E. integriceps

Multiple copulation was commonly observed in all Pentatomoidea studied. The first mating always occurred before oviposition but

the process was usually repeated three to six times during oviposition and often shortly before egg laying. Thus, the following experiment was carried out, to see whether multiple copulation effects fecundity.

Fecundity of E. integriceps with Single Mating.

The conditions were similar to those in experiment No. 1 with barley grain and water. These were 20 replicates , and the tests carried out at 28.5°C. After the first copulation the males were removed from the breeding cages. The changes in the weights of the females were similar to those in experiment No. 1.

The mean of daily eggs per female and the mean of the total fecundity, were also similar, and are depicted in fig. 22 . The details of the data are given in Appendix X. The results are summarised in Table 10.

Table 10. Oviposition of E. integriceps at 28.5°C, fed on barley grain and water. Single mating.

Pairs No. (Replicates)	Longevity of females in days	Fecundity per female			
		No. of batches		No. of eggs	
		Limits	Mean	Limits	Mean
20	50.8	2 - 23	14.0	41 - 301	180.3

The effect of single and multiple matings are compared in Table 11.

A comparison of data in Table 11 and that in Fig. 22 indicate that fecundity has increased only very slightly when there were multiple copulations, but that longevity of these females was much shorter than in those which had mated only once.

Table 11. Fecundity of E. integriceps in Relation to Copulation (Food barley grain and water)

No. of females (Replicates)	Temperature °C	No. of copulations	Mean longevity in days	Fecundity per female	
				No. of batches	Total No. of eggs
20	28.5	Single	50.8	14.0	180.3
25	28.5	Multiple	38.6	14.4	183.0

D) Relationship between Crowding and Fecundity

Preliminary experiments were set up to study the effect of crowding on fecundity and the length of the life cycle of E. integriceps kept at 28.5°C and fed on barley or wheat grain, and water. All replicates of both series were kept in polystyrene cages of the second design. Sufficient food was provided every other day. The counting of the eggs was carried out twice a day between 9 - 10 in the morning and in the evening throughout the lives of the insects. For comparison the mean fecundity per female bred in pairs is also included. The experiments can be divided in the following order, in relation to the food provided:-

1. Effect of Crowding on Fecundity and Longevity of E. integriceps at 28.5°C; food - barley grain and water.

Level of Crowding: 10 pairs in each replicate

Ten pairs of Eurygaster were bred in each cage and the experiment was repeated 10 times. The femaleslaid most of their eggs on muslin, and cardboard. The number of eggs in batches was

more variable than when there was only one pair per cage. The females were often disturbed by the males while ovipositing. The details of the data are given in Appendix XII.

The results are summarised in Table 12 and are depicted in fig. 23.

Table 12. Effect of Crowding on Fecundity and Longevity of E. integriceps bred on barley grain and water at 28.5°C

No. of replicates	Level of crowding (pairs)	Mean longevity in days		Mean Fecundity per female	
		Male	Female	No. of batches	No. of eggs
25	1	27.2	38.6	14.4	183.0
10	10	26.5	32.6	7.8	112.4

Results: Both fecundity and longevity decreased under crowded breeding conditions.

2. Effect of Crowding on Fecundity and Longevity of E. integriceps at 28.5°C; food - wheat grain and water

Level of Crowding: 5 pairs in each replicate.

Five replicates each with 5 pairs of Eurygaster were used in this experiment. The females laid mostly under or on muslin and cardboard. The numbers of eggs per batch were variable but most of the eggs were laid in batches of 13 and 14. The details of the results are given in Appendix XI. The results are summarised in Table 13 and are depicted in fig. 23.

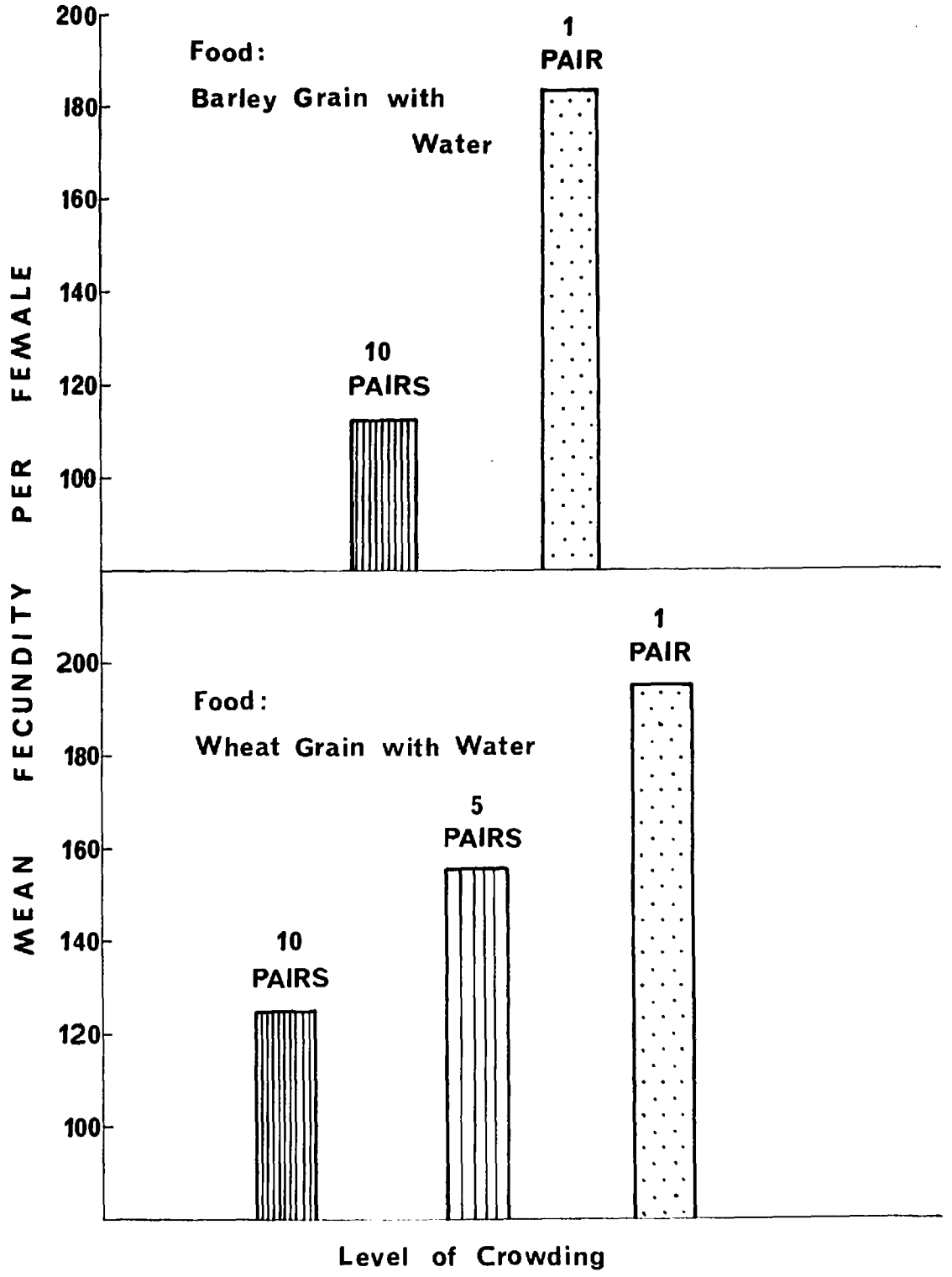


Fig.23.EFFECT OF CROWDING ON FECUNDITY OF Eurygaster integriceps AT 28·5°C

Level of Crowding: 10 pairs in each replicate.

Ten replicates each with 10 pairs of Eurygaster were used. Variability of the number of eggs per batch was great and ranged from 1 to 27; the batches of 10, 13 and 14 were the most common. The details of the data are given in Appendix IVa. The results are summarised in Table 14 and are shown in fig. 23.

Table 14. Effect of Crowding on Fecundity and Longevity of E. integriceps bred on wheat grain and water at 28.5°C

No. of replicates	Level of crowding (pairs)	Mean longevity in days		Mean Fecundity per female	
		Male	Female	No. of batches	No. of eggs
25	1	39.0	50.1	15.6	195.2
5	5	27.8	41.9	11.9	155.0
10	10	19.8	24.1	9.3	124.2

Results: Both fecundity and longevity decreased in relation to the level of crowding, on wheat grain and water.

Neottiglossa pusilla (Gmelin)

1. The habitat.

This species was always collected in the same habitats as Aelia acuminata, in and around Silwood Park.

The sites selected for its study were therefore also the same as those of Aelia (see page 65). It was collected by sweeping of warm, open grassy areas surrounded by tall trees. In and around Silwood Park, this species is rarer than A. acuminata. The maximum number in a 100 sweeps was 5 and these were taken in early June on the North and South Gravel. This shieldbug was also collected on the Cricket Hill in Hampshire.

2. The host plants

The common species of plants, on which N.pusilla was found were Poa, Festuca and rarely, Agrostis. At Silwood Park it was usually found on Poa pratensis, P. triviulis, Festuca rubra and occasionally on Agrostis tenuis. It has also been reported on other graminaceous plants (see Puchkov, 1961), and from some Compositae and Leguminasae (see Butler, 1923 and Puchkov, 1961).

Poa and Festuca are common in Britain and flower in late May or at the beginning of June. The grasses tend to die after flowering and accumulate as litter, which serves as a hibernation site for the adults of Neottiglossa, Aelia and many other insects.

Poa and Festuca are indigenous to Europe, Asia and North America (Thomas and Davies, 1952).

3. Description of stages: (see Butler, 1923; Puchkov, 1961and page 97).

4. Occurrence of Adults

In 1965 and 1966, the overwintered adults of N. pusilla appeared on grasses as early as the middle of May at Silwood Park and Cricket Hill. Towards the end of May and the beginning of June they occurred on Poa and Festuca spp. at North and South Gravel as well as on the Heath.

5. Reproductive Biology

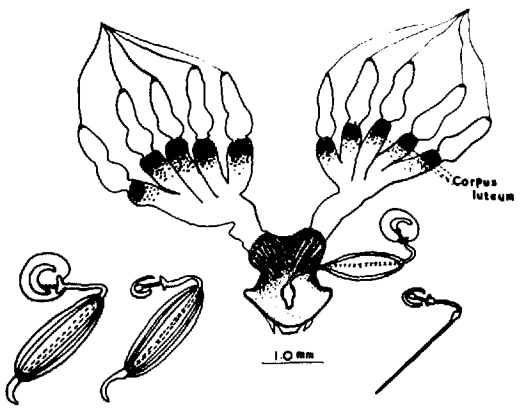
A) Reproductive Organs.

The morphological characters of female and male reproductive organs are shown in fig. 24 . The general descriptions of both sexes are similar to those of A. acuminata, except that in the female of N. pusilla each ovary has five ovarioles (six in Aelia).

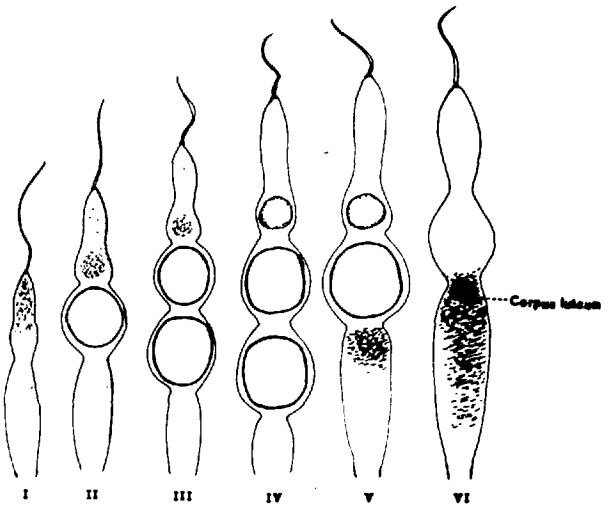
6. Sexual Maturation

a) Diapause:

Neottiglossa pusilla is a univoltine species with an obligatory diapause similar to Aelia. The new generation appears from early August to the end of September. These bugs are faintly brownish and do not mature until about November. They overwinter as adults near the bases of the grasses, being very close to their breeding areas and remain there until the following May. During the winter the colour of the pronotum, scutellum and fore-wing gradually change to a brighter colour at the end of April and in May the bugs are sandy to greyish. At this time the reproductive organs are mature and reproduction occurs in temper-

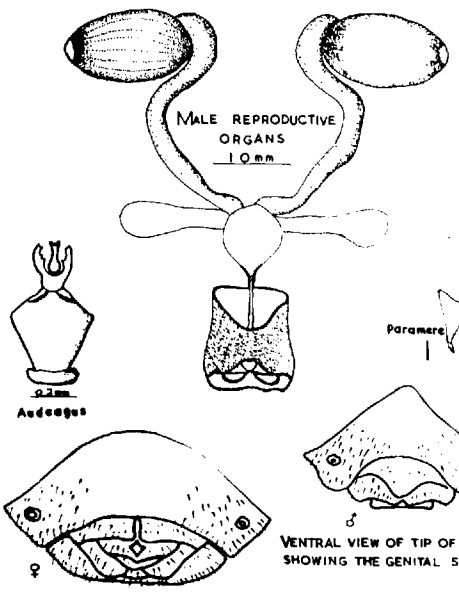


FEMALE REPRODUCTIVE ORGANS
IN POST OVIPOSITION PERIOD
WITH DIFFERENT ASPECTS OF SPERMATHECA

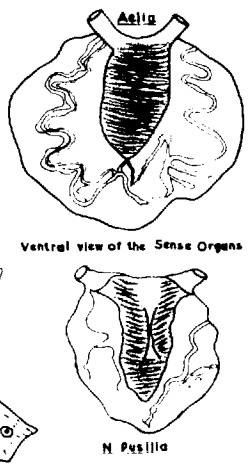


DIFFERENT STAGES OF OVARIAL DEVELOPMENT

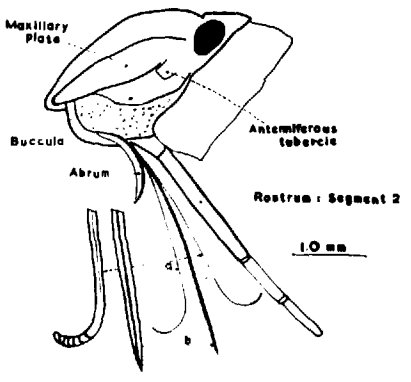
0.5 mm



VENTRAL VIEW OF TIP OF ABDOMEN
SHOWING THE GENITAL SEGMENTS



Ventral view of the Sense Organs



a) Mandibular Stylet
b) Maxillary Stylet

SIDE VIEW OF HEAD SHOWING THE MOUTHPARTS

FIG.24. NEOTTIGLOSSA PUSILLA (GMELIN)

ature over 20°C in the field and in the laboratory.

b) Changes in Reproductive Organs on Maturation

This is similar to that of A. acuminata, but, in the female, six stages of ovarial development were observed which are shown diagrammatically in fig. 24 . The difference is that in N. pusilla the IVth and Vth stages are combined and represent the IVth stage. The corpora lutea are not visible at this stage. The rest of the description of the stages are similar to those in Aelia. The form and sculpture of the eggs are distinctly different from Aelia.

7. Fecundity in Captivity and in the Field

In the field, mating was observed in early June in 1965 and the first batches of eggs were found on 5th June. The last batches of eggs were laid by females in breeding areas in about the middle of July, at Silwood.

The fecundity varied from 20 to 60 eggs per female. The eggs were laid under leaves, on stems and ears of Poa and Festuca species.

In the laboratory the bugs were bred on grain of wheat and barley with water at 28°C. The number of eggs was much less than in Aelia. The average for six females was 56 ranging from 15 - 70. At 20°C the female laid only one or two batches of 10 eggs. The number of eggs in each batch was mostly 10 and they were laid in two or three rows. This is related to the number of ovarioles which are 10 in N. pusilla.

Thus, this observation does not confirm Xambeu (in Butler, 1923) and Southwood and Leston (1959) who report that N. pusilla lays batches of 12 eggs. It is probable that both authors have described the eggs of A. acuminata as the batches of eggs of this pentatomoid are similar to that of N. pusilla but contain 12 eggs.

8. Rearing of Larval Instars of N. pusilla

In the field rearing was carried out in celluloid cages of standard size. The insects were fed on Poa and Festuca with ears. In 1965 the first instars hatched on 15th June. By early July third instars occurred and on the 28th of this month the first brownish male of the new generation was observed. In the laboratory N. pusilla were reared on wheat and barley grain at 28°C. The duration of development of this pentamoid was slightly shorter than that of Aelia. In the field the adults of old and new generations were always captured about ten days earlier than Aelia.

9. Migration

At Silwood and in Yateley N. pusilla leaves its breeding areas in late August and during September. In October of three seasons (1964 - 66) all attempts to find this pentatomoid in and around its breeding field were unsuccessful. N. pusilla was never seen to fly, but because of its absence from the breeding areas, it seems probable that the bugs migrate to the nearest trees around the areas similarly to Aelia. Later towards the end of October or early November they go to their hibernation sites near the bases of the clumps of grasses.

Palomena prasina (Linnaeus)

1. The habitat.

Palomena was found in the same habitats as Aelia acuminata, Piezodorus lituratus and Neottiglossa pusilla, i.e. at Silwood it was found in grassland and occasionally on broom bushes in the broom areas. The second and third instar larvae were always collected from grasses but the later stages from broom, bramble bushes and from birch trees in July and in early August. A meadow with rye-grass, broom and bramble bushes, surrounded by trees such as birch hazel and oak was the habitat for the green stink bug.

Palomena is widely distributed in Britain and is recorded from all the coastal counties (Butler, 1923 and Southwood and Leston, 1959).

2. The host plants.

At Silwood Park the adults of Palomena occur in early June on broom, bramble bushes, meadow grasses as well as on hazel and birch. The adults feed on the buds, pods and the leaves of these plants. By the end of June and during July the second and third instars appear on Poa pratensis, P. trivialis, Lolium perenne and occasionally on Festuca rubra, where they feed abundantly on the fruits until the grasses become dry. The fourth and fifth instars, however, leave the

grasses and climb on to the surrounding bushes and trees, where they feed on the fruits. They complete their development in September. The adults of the new generation leave the habitat after a week or more and fly towards larger trees such as the sweet chestnut, horse chestnut and oak.

Palomena has a wide distribution throughout the greater part of the Palaearctic region and in the African and Asiatic regions (Butler, 1923 and Puchkov, 1961). It has been reported as an important pest on hazel nut trees in Sicily (Boselli, 1932). Its early instars have also caused damage to rye and corn in Lauenburg in Germany. After the rye-fields are harvested in August the fourth and fifth instars move to the adjacent potato fields, or, on to soft fruits (Tischler, 1937 and 1938).

Palomena has also been reported from south-west U.S.S.R. as a minor pest on Lupin and Vicia. It is, however, a polyphagous species and has been recorded on many herbaceous plants, bushes and trees (see Puchkov, 1961).

3. Description of Stages

Description of immature and adult stages have been given by Butler (1923); Boselli (1932) and Tischler (1937).

4. The Number of Adults and Larval stages of P. prasina.

The number of adults of both overwintered and of the new generation of Palomena was very low during the three seasons. This number ranged from 1 - 3 per 100 beats of broom, or sweeps

of grasses on the Heath. The bugs occurred as early as 27th and 30th of May in 1964 and 1966 respectively, but the maximum occurred during the last two weeks in June. The nymphs were collected mostly in July and August. Their number was variable in different stages and different years. The first four stages were more common and up to 10 of each stage were collected at higher day temperature of the last week of July and the first two weeks of August in the three seasons. The fifth instars were less common and only up to 5 were collected in samples on broom, gorse, brambles and hazel in late August and during September. Several individuals of the adults of the new generation were collected on the bushes and trees around the meadows, in September and in early October.

5. Reproductive Biology.

The female has a pair of ovaries each consisting of seven ovarioles. In the male there are a pair of testes similar to those in P. lituratus.

6. Sexual Maturation.

a) Diapause:

Palomena is a univoltine species in southern England having an obligate diapause which terminates in early winter. Similar to Piezodorus there is a colour change in P. prasina from a dark brownish-green on the head, pronotum and scutellum in the adults of the new generation in autumn to green in spring. Tischler (1938) explained this colour change as a winter-adaptation in Palomena. He suggests that laboratory

experiments must be made to see if the whole problem is based on hormonal processes. Dupuis(1949), Schiemenz(1953) say that the colour change in Palomena is due to the complex changes in the disposition of the black (melanin) pigment, which is possibly caused by a reduced rate of metabolism. The author is inclined to think that the colour changes in Palomena, Piezodorus and Neottiglossa are hormonal processes which are related to the diapausing period of these Pentatomoidea. The insects do not mature sexually before these changes occur and diapause is terminated.

b) Changes in the Reproductive Organs on Maturation:

In the male the changes are similar to P. lituratus. These changes in the female are like those in Eurygaster but the eggs are dark green and longer (1.3 mm; average) and up to three developed eggs can be seen in the Vth stage of ovarial development.

7. Fecundity in Captivity and in the Field.

Very little observations were made as there were only a few Palomena. In the field copulation and oviposition was observed in June and July on warm days of 1964 - 66. The females oviposited the egg batches in a hexagonal shape on leaves and fruit of broom, brambles, oak seedlings and also on ears of Poa spp. The number of eggs in each batch was usually 28 but varied from 7 to 42; batches of 28 being in four rows each consisting of seven eggs attached together. The females laid

their eggs often on the upper parts of the plants about 1 - 2 m from the ground surface. The fecundity per female bred on buds and pods of broom varied between 28 to 83 eggs. In the laboratory the average fecundity of five females was 42 eggs. Boselli (1932) reported that fecundity in Palomena may be near to 100 per female in Sicily.

8. Development of the Larval Instars and their Food:

During July and August the first four larval instars were found on grasses and particularly on Poa spp. The ears of grasses were essential for the growth of the larval stage. All attempts to rear different instars to adult on pods of broom failed. In the late period of fourth instars and in fifth instars Palomena left grasses and climbed on to brambles, hazel and even on to oaks in their habitat, and fed on their fruit in September. The duration of larval instars varied between 67 to 85 days in the three seasons. Compared with the other Pentatomoidea the period of development of immature stages of Palomena was much longer than the other species studied. The adults of the new generation appeared towards the end of September. They fed for about ten days before migrating on to the tall trees surrounding the meadow and the broom fields.

Piezodorus lituratus (Fabricius)

1. The habitat.(see page 19)

2. The host plants.

Piezodorus lituratus is one of the commonest British pentatomoids and is found on two leguminous shrubs, i.e. on gorse (Ulex europaeus) and broom (Sarothamnus scoparius).

It has also been reported on other leguminous plants by Butler (1923) and on Lupinus angustifolius, L. albus, sulla (Hedysarum coronarium) by Boselli (1932) and by Puchkov (1961), in wheat fields on Centaurea iberica by Brown (1966).

Although Piezodorus feeds on many leguminous plants, the main host plants in England and Scotland seem to be Ulex and Sarothamnus.

a) Ulex europaeus generally flowers in spring and has two main growth periods. One in spring and the second after pod formation. The adult Piezodorus feed on the buds, pods and new green leaves but show a preference for buds when they are available. The larvae also feeds on pods and seeds, although it may feed on green leaves.

Gorse grows in rough grassy places and on edges of heaths, usually on the lighter and less calcareous soils. It is widely distributed in the British Isles and is abundant in England.

In Europe it is distributed from Scandinavia to Spain and Portugal (Clapham, Tutin and Warburg, 1952), but has an Atlantic distribution.

b) Sarothamnus scoparius (L.) Wimmer, is a common shrub of sandy wastelands and on disturbed soils. In Europe it is found from Scandinavia to Spain and to the Canary Islands, but does not extend eastwards of Poland and Hungary in central Europe (Clapham, Tutin and Warburg, 1952).

The leaves of broom appear in Spring and may start falling as early as the middle of September. Flowering usually occurs in May but the time of flowering may vary from year to year. The overwintered Piezodorus are attracted by flowers and at Silwood appear on broom in May. They feed on buds and later on pods, twigs, leaves, but showing a preference for buds, when they are available. The larvae, show preference for pods and seeds but will feed on twigs and leaves.

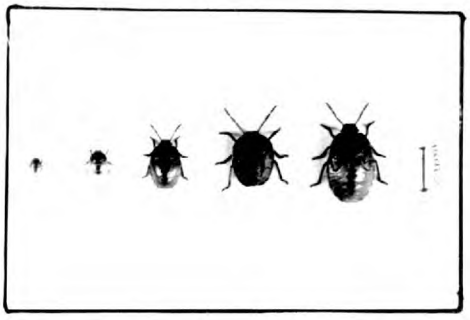
Broom has two growth periods during the year, one in Spring before flowering and the second after pod formation.

3. Description of Stages.

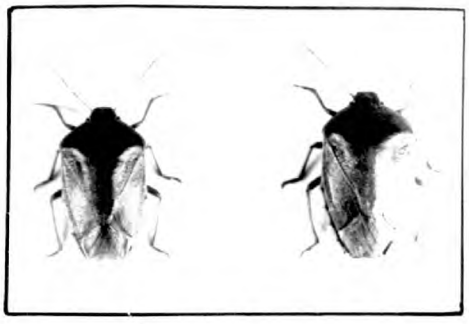
Descriptions of adults and immature stages are given by Butler (1923) Boselli (1932). Different stages of P. lituratus collected in the field are illustrated in fig. 25.

4. Time of Occurrence of Adults.

Piezodorus was often the first Pentatomoid to occur in

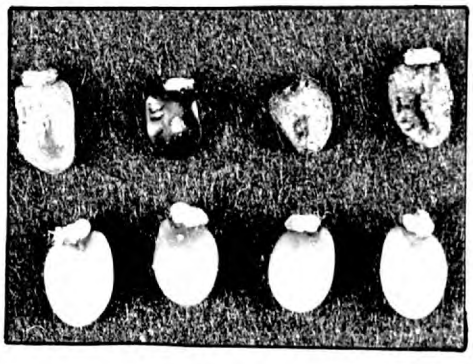


Larval Instars



A Pair of Adults. Female (right)

A Type of Damage of Broom Twigs
(Left - healthy twig)



A Type of Damage of Broom Seeds
(Bottom row - healthy seeds)

Area A "New Broom" Selected Habitat for the study of Population

Fig. 25.–Piezodorus lituratus (F.)

the field in spring in southern England. At Silwood the overwintered adults of Piezodorus appeared in May. The earliest record is on the 27th of April in 1964. In the New Forest and Yateley Piezodorus were collected as early as the middle of April in 1965 and 1966. During the three seasons the bugs were usually observed emerging from the bases of the grasses when the soil temperature was over 13°C. The manner of their emergence was similar to that of Aelia, but they were seen to fly to gorse, or broom, which were in flower at that time.

5. Estimation of Numbers of Adults and Larvae of P. lituratus during the three Seasons

This part of the survey started in June 1963 and was continued in 1964 and 1965. The method used for estimating the population was by beating approximately 1/8th of broom bushes on to a cloth tray in Area A (see page 19). The adults and the immature stages of bugs that fell on the tray were collected. Weekly samples consisted of a 100 beats of different bushes in Area A. These were made from April to October each year (see page 26).

The general rise and fall in overwintered and offspring and their larval instars in 1963 - 65 derived from this method of sampling is shown in fig 26 . The number of Piezodorus and its immature stages in samples was greatly influenced by the prevailing temperature. This is illustrated in fig. 27 . In the same figure the soil temperature for 1965, taken at time of sampling, from the bases of the grasses under broom, is also included. During cold periods and rain Piezodorus and its larval instars usually stayed on the lower

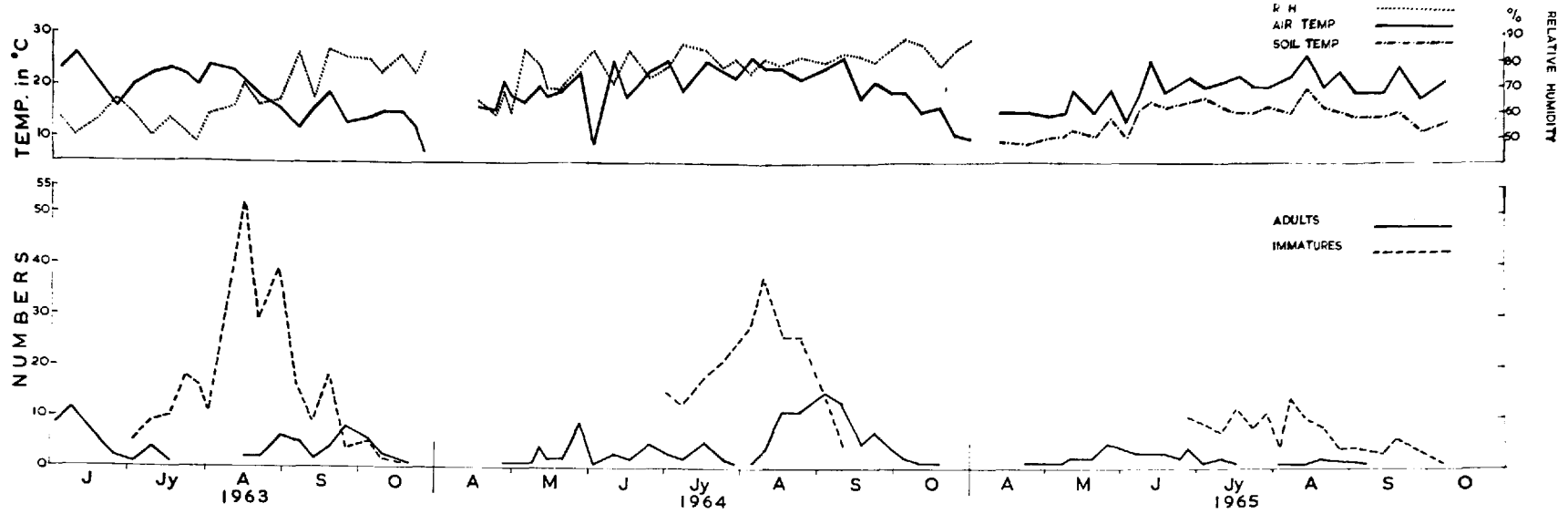


Fig. 26.–Seasonal Changes in the No. of Piezodorus lituratus on Broom in Relation to Temperature and Relative Humidity

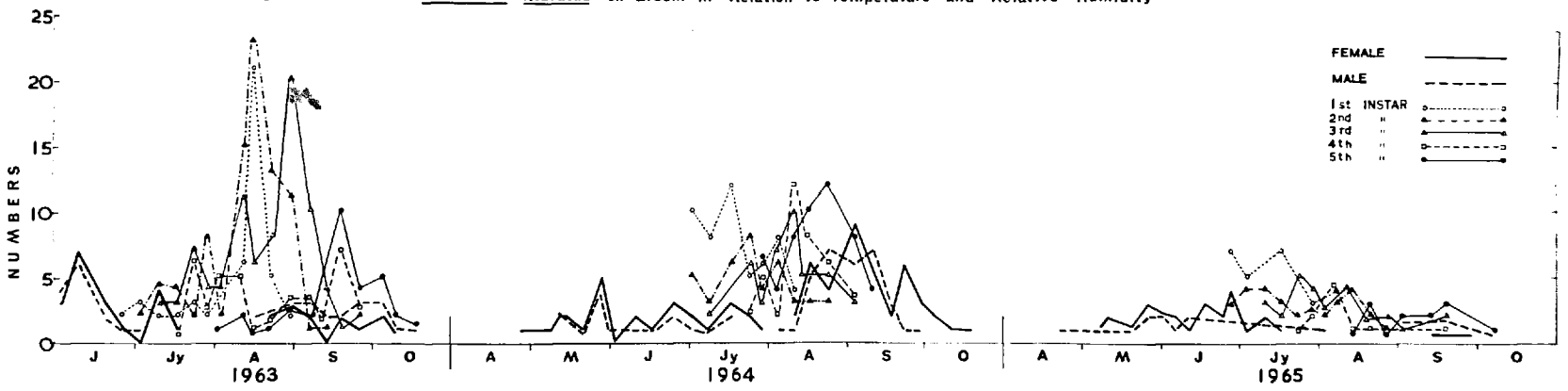


Fig. 27.– Seasonal Changes in the No. of Adults and Larval Instars of Piezodorus lituratus on Broom

parts of broom, or on the ground among the grasses. They reappeared on the branches again as temperatures rose. Thus, population estimates derived by beating during cold periods can be considered to be estimates of the numbers on the branches only. The fall in the number of Piezodorus due to the fall in temperature can be seen in fig. 26 in June 1964.

Sampling data and temperatures taken on the days of sampling are summarised in Table 15.

Table 15. Population estimation of Piezodorus lituratus during Three Seasons

Date	Weekly Samples No.	Each sample is the Number beats of 1/8th bushes (broom) = 100									Mean air temp. in °C in period of sampling
		IMMATURE STAGES					ADULTS				
							Overwintered		Offspring		
		I	II	III	IV	V	Male	Female	Male	Female	
1963	21 (3.6-17.10)	48	86	83	38	34	14	19	20	13	18.9
1964	27 (27.4-18.10)	53	41	42	38	52	14	27	32	42	20.7
1965	24 (22.4-7.10)	26	31	30	12	13	9	25	4	1	19.7

The date of first and last samplings are in brackets.

It can be seen that the numbers of Piezodorus adults and larvae sharply decreased in 1965. One possible reason for this, was that the broom bushes were ageing, and some were partially dead, in 1965. They had few buds and pods to attract Piezodorus. Parasites and predators may also have been responsible for this decline in numbers.

No conclusions can be drawn, as the factors that effect the

numbers, have not been studied. Moreover, the population was so small that no statistical analysis can be applied to the data.

6. Biometrical Differencers in Adults and Larval instars of Piezodorus lituratus

As in many other insects, there is variation in size of the different individuals of adults and larval instars in most Pentatomoidea. This caused certain difficulties in indentifying the larval instars of closely related species.

In some species of shieldbugs such as in Piezodorus, there is also much variation in colour of the immature, as well as of the adult stages, which often adds to this problem. In such cases, mean measurements of some parts of the body were a help. The means were taken from the specimens collected from different localities and hosts.

In P. lituratus the length and width of body, head, pronotum and the length of antennae, rostrum and the hind leg were measured in ten specimens of each stage. The insects were collected from different fields in southern England on broom and on gorse, and the data are given in Table 16.

7. Reproductive Biology

Reproductive Organs

The morphological characters of female and male reproductive organs are shown in fig. 28 . The female has a pair of ovaries each having seven ovarioles. In the male there are a pair of ovoid testes and accessory glands which open into the vesicula seminalis. The rest of the organs are as in the preceding species.

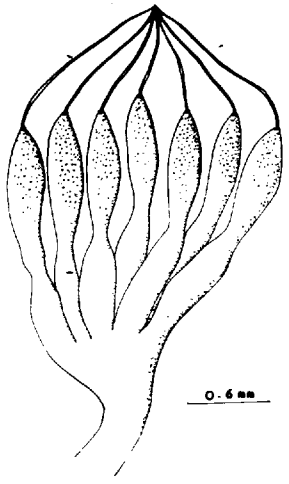
T A B L E 16.

Biometrical measurements of Adults and Larval instars of Pezodorus lituratus

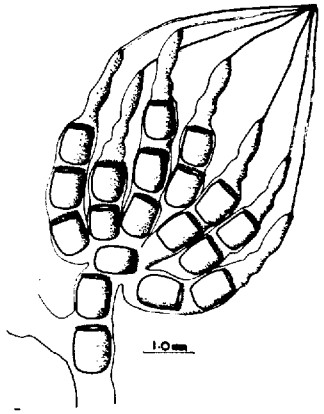
Stages	Body		Head		Pronotum		Antennae	Rostrum	Hind leg	
	Length	Width	Length	Width	Length	Width	Length	Length	Femur	Tibia
1st	2.3 (1.6-2.3)	1.4 (1-1.9)	0.5 (0.4-0.6)	0.94 (0.8-1)	0.43 (0.3-0.5)	1.41 (1-1.7)	1.41 (0.07-1.6)	1.44 (1.2-1.7)	0.55 (0.3-0.7)	0.6 (0.3-0.7)
2nd	2.9 (2.6-313)	1.9 (1.5-2.4)	0.68 (0.5-0.8)	1.22 (1-1.4)	0.56 (0.5-0.6)	1.77 (1.4-2.2)	1.9 (1.4-2.2)	1.81 (1.4-2.5)	0.84 (0.6-1)	0.93 (0.7-1.1)
3rd	3.9 (3.4-4.5)	2.8 (2.5-3.1)	0.9 (0.8-1.2)	1.39 (1.2-1.5)	0.81 (0.7-0.9)	2.29 (2.1-2.4)	2.19 (2 -2.5)	1.9 (1.7-2.2)	1.09 (0.9-1.2)	1.18 (0.9-1.3)
4th	4.99 (4.6-5.5)	3.6 (3.4-4.3)	1.01 (0.9-1.2)	1.83 (1.6-2.1)	0.97 (0.8-1.2)	3.28 (3-3.6)	2.68 (2.1-3.4)	2.62 (2.3-3.7)	1.47 (1.3-1.5)	1.67 (1.5-1.8)
5th	8.34 (7-9.7)	5.55 (5-6)	1.30 (1-1.5)	2.32 (2.1-2.8)	1.59 (1.3-1.8)	4.84 (4.3-5.2)	4.18 (3.7-4.5)	3.41 (3.1-4)	2.36 (2.1-2.7)	2.33 (2.1-3)
Male	9.53 (9.5-12)	6.20 (5.3-7)	1.88 (1.7-2)	2.70 (2.5-2.9)	2.89 (2.5-3.3)	6.11 (5.2-7)	5.33 (4.8-5.8)	4.13 (3.9-4.4)	3.61 (3-4)	3.36 (2.9-3.8)
Female	11.26 (10-12.2)	6.41 (6-7)	1.81 (1.4-2)	2.75 (2.6-2.9)	2.91 (2.6-3)	6.21 (5.5-7)	4.86 (4.4-5.5)	4.07 (3.9-4.3)	3.65 (3.3-4)	3.42 (2.9-4)

Note: 1) All measurements are in mm and are the mean of 10 specimens collected from different habitats.

2) Limits in brackets.



RIGHT OVARY AT MATURATION



MATURED OVARY , STAGE IV
SHOWING DEVELOPMENT OF 3 EGGS PER OVARIOLE
AND MATURED EGGS IN LATRAL AND COMMON OVIDUCT

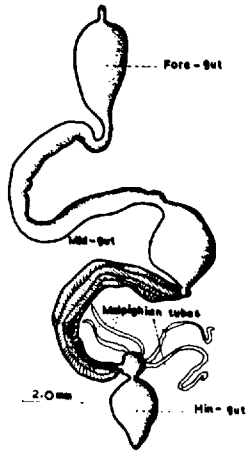
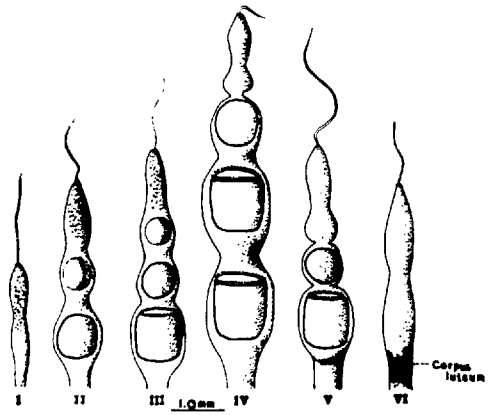
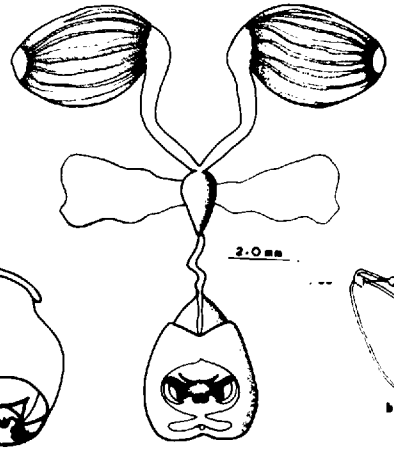


DIAGRAM OF ALIMENTARY CANAL

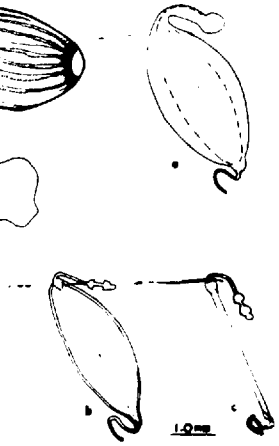


DIFFERENT STAGES OF OVARIAL DEVELOPMENT

AEDEAGUS



MALE REPRODUCTIVE ORGANS



a,b,c SPERMATHECA

FIG.28-PIEZODORUS LITURATUS (F.)

8. Sexual Maturation

a) Diapause:

In southern England P. lituratus is univoltine, with an obligatory diapause, during which the colour of the insects is characteristic. Diapause terminates in early winter.

b) Colour Changes:

Both sexes of the offspring of P. lituratus are reddish-brown in late summer and in early autumn months, but coloration gradually changes to bright green in spring. Boselli (1932) in Sicily, and Woodward (1949) in southern England, have observed the colour changes in Piezodorus during its aestivation and hibernation periods. The latter author says, "although the males had sperm in testes and vasa deferentia in December, the females are not fertilised until spring." Dupuis (1952) further studied the colour changes in P. lituratus in Morocco and France; he reported this phenomenon as probably related to diapause which affected the physiology of the insect.

In the present study the colour changes in P. lituratus were investigated. The offspring of Piezodorus were kept within the cages before their migration and were inspected every 3 - 5 days from August to May. In both sexes there was a gradual change in colour of the pronotum, scutellum and elytre from burnt-sienna (reddish-brown) in August and September, to dark bluish-green in October and November; later, in December and January, the bluish colour gradually disappeared and the bugs became deep green. Finally,

in March and April, their colour turned to bright green. The period of colour changes differed between the individuals of the Piezodorus. In most of the bugs which completed their larval development in August and early September, the green colour appeared mostly in winter.

In some specimens which were collected in the New Forest on 14.8.65 and were kept in cages at Silwood, the survivors had a brownish colour as late as in early March, but later they became green, by the end of April 1966. In all experiments only the bugs with the bright green coloration were able to mature sexually, both migrated, or non-migrated individuals. Thus, colour changes in this Pentatomoid, are associated with the physiological development of the sex organs.

c) Changes in Weight of the Adults

Similar to Eurygaster there was a gradual increase in weight after diapause in both sexes, which then fluctuated every two to three days in laboratory cultures. This fluctuation is shown in fig. 30 in two females taken at random.

d) Changes in the Reproductive Organs on Maturation

These changes in the male appear in the testis, accessory glands, and in the seminal vesicles. In the female, the changes are easily seen in the development of the ovarioles and spermatheca. In 1965 the ovarial developments were studied by dissections of 3 - 5 females every week, from early May to October. The general changes were similar to those described for A. acuminata, except that in Piezodorus the IVth and Vth stages are combined and corpus luteum is not visible. The eggs are light cream within the females and change to black with a cream ring in the middle and around the opercula after they are laid. The morphological changes in the ovarioles are shown in fig. 28.

9. Fecundity in the Field and in the Laboratory

The overwintered P. lituratus used were collected in the field shortly after emergence from their hibernation sites, in late April and in May at Silwood and at Yateley.

1. Fecundity in the Field

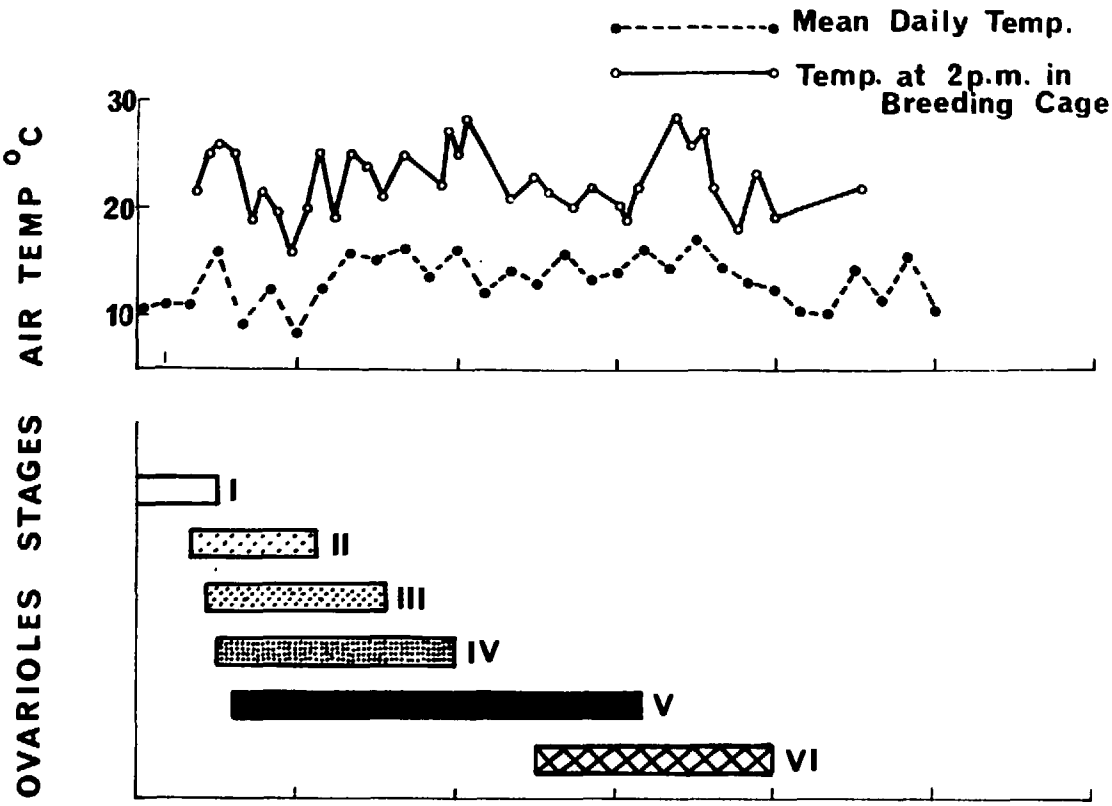
The cages used were made of celluloid cylinders and muslin, of standard size, or second design (page 30). They were placed on the branches of broom or gorse, which were rich in buds in May and June, and pods in July, August and September. The fresh branches of broom were removed every 7 - 8 days. The overwintered Piezodorus preferred to feed on buds of broom and gorse when these were available, but they also fed on leaves and twigs.

In 1965, the two following series of experiments were set up to find out the fecundity of P. lituratus in outdoor conditions.

Series A: Fecundity of P. lituratus on Broom

Fifteen pairs of bugs were bred separately on this diet. The experiment started on the 6th May and ended on the 12th September 1965. The counts of eggs laid were made every day, or every other day. Besides the fecundity, longevity, distribution of oviposition sites and the air temperature during the life span of the females, were also recorded. The detailed data are given in Appendix XIII. The results are summarised in Table 17.

The mean number of eggs per female per day is plotted against time and is shown in fig.29 in which the mean daily air temperature and that of the cages at 2 p.m. taken within the cages near the insects, are



STAGES OF OVARIAL DEVELOPMENT OF P.lituratus IN THE FIELD IN 1965

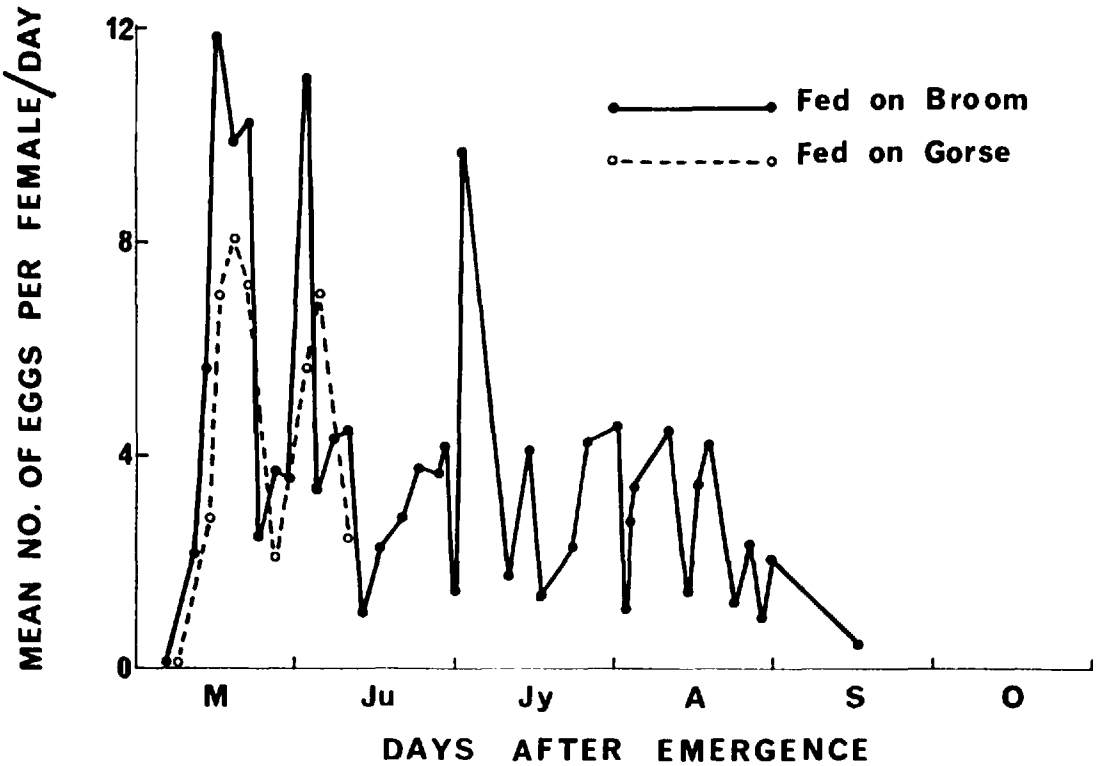


Fig.29.-THE FECUNDITY OF Piezodorus lituratus IN THE FIELD IN 1965

included. In the same figure, the stages of ovarial development in Piezodorus in 1965 are depicted; these were studied by weekly dissections of 3 - 5 females collected in the field.

Table 17. Fecundity, Longevity and Distribution of Oviposition sites of Piezodorus lituratus fed on broom in the field in 1965.

Pairs (No. of replicates)	Mean Longevity in days		Mean fecundity per female		Oviposition sites Average eggs per female				Mean air temp °C
	Male	Female	No. of batches	Total eggs	Leaves	Muslin	Pods	Twigs	
15	58.8	99.8	10.26	148.5	20.3	41.8	30.9	55.5	13.1

The highest number of eggs was laid during the last two weeks of May and in June and July. The peaks of oviposition are in the third week of May, on the third day of June, and on the second day of July. In late May and in mid June fecundity had sharply decreased. Clear relationship emerged between temperature and the rate of oviposition. High temperature stimulates oviposition of Piezodorus, and the females lay eggs in the warmer hours of the day.

Series B: Fecundity of P. litruatus on Gorse

This was similar to the previous experiment, but the bugs were provided with branches of gorse which had buds and pods. The pods of gorse tended to dry rapidly and the bugs were seen feeding on the seeds as well. Five replicates each with a pair of Piezodorus were used. The experiments started on the 6th May and ended in late June 1965. The detailed data are given in Appendix XIV. The results are summarised in Table 18.

Table 18. Fecundity, Longevity and Distribution of Oviposition sites of P. lituratus in the field, fed on gorse in 1965

Pairs (No. of replicates)	Mean Longevity in days		Mean fecundity per female		Oviposition sites Average eggs per female				Mean air temp. °C
	Male	Female	No. of batches	Total eggs	Leaves	Muslin	Sepal	Spine	
5	28.6	35.6	2.8	42	8.8	12.8	14.2	6.2	12.5

A comparison of fecundity and longevity of Piezodorus fed on broom and on gorse indicated that both are much higher when the bugs are bred on broom. This may be due to the availability of more nutritive on the pods of broom which remain fresh longer than those of gorse in normal conditions. Fresh gorse pods, however, are uaually available throughout the spring and summer, and the fecundity of the bugs fed on gorse may be higher than that indicated by this experiment.

2. Fecundity in Captivity

The cages used were polystyrene boxes of the second design, and the food in the form of fresh twigs of broom, or gorse with buds and pods (see page 43).

Two sets of experiments each with 20 replicates were carried out at 20°C and 28°C. A pair of Piezodorus was used in each replicate. Besides fecundity, longevity, distribution of oviposition sites, and weight of females, were also studied. The changes in weight in randomly taken females at both temperatures are shown in fig. 30. The counts of eggs were made daily between 10 - 12 a.m.

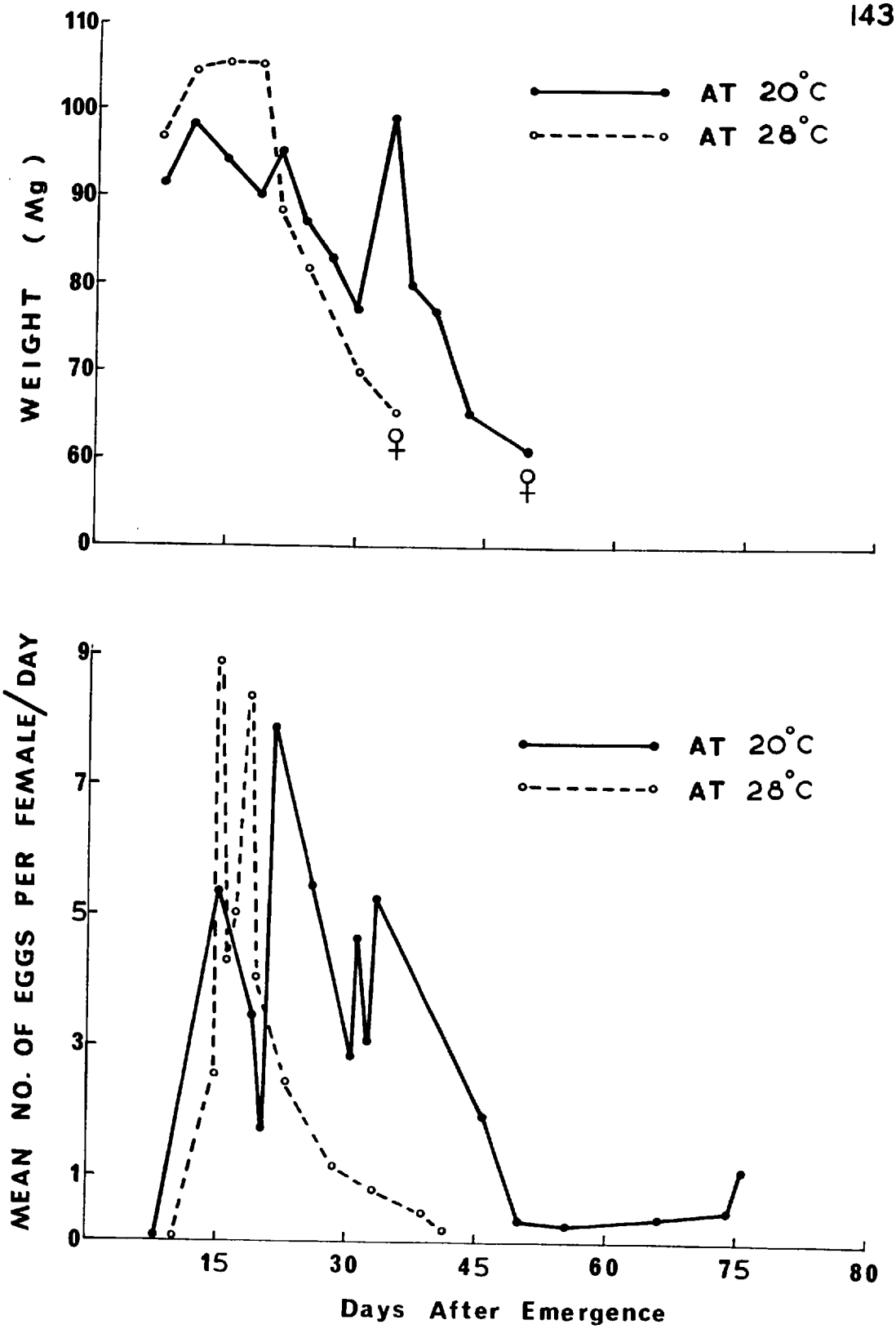


Fig.30-The Relationship between Temperature and Fecundity in Piezodorus lituratus

The details of the data are given in Appendices XV and XVI. The results can be summarised in the following Table 19.

Table 19. Fecundity, Longevity and Distribution of Oviposition sites of P. lituratus fed on broom at 20°C and 28°C and 75% R.H.

No. of females (replicates)	Temperature °C	Mean Longevity in days		Mean No. of eggs per female		Oviposition sites Average eggs per female		
		Male	Female	No. of batches	Total eggs	Leaves and Plastic	Pods	Muslin
20	20	35.3	37.8	2.45	44.9	0	3	41.95
20	28	20.5	30.4	2.5	38.7	2.2	0	36.5

The mean number of eggs per female per day for both temperatures are plotted against time and are shown in fig. 30.

A comparison of data clearly indicate that both longevity and fecundity have decreased at 28°C. This is very interesting in relation to the distribution of Piezodorus and confirms that contrary to A. acuminata and E. integriceps, the present shieldbugs would not multiply in high numbers in the warmer parts of its region of distribution, such as Morocco.

3. Fecundity and Longevity of Crowded P. lituratus on Broom at 20°C

Level of Crowding: 5 pairs in each replicate

The bugs were bred in the same cages as in the previous experiments. Sufficient food was provided every other day. The counts of eggs were made twice a day in the morning and in the evening.

The details of this experiment are given in Appendix XIVa. The results can be summarised in the following Table (20).

Table 20. Fecundity and Longevity of Crowded P. lituratus on Broom at 20°C and 75% R.H. Level of Crowding: 5 pairs

No. of Replicates	Mean Longevity in days		Fecundity per five females		Mean Total No. of eggs per ♀
	Male	Female	No. of batches	Total eggs	
6	13.26	17.7	6.8	118.1	19.68

When the results of breeding Piezodorus as single pairs and 5 pairs in each replicate are compared, it can be seen that both longevity and fecundity sharply decrease under crowded conditions.

4. Rearing of Larval Instars of P. lituratus

The following experiments were carried out to study the effect of food and temperature on development of larval instars of Piezodorus in the field and in the laboratory.

a) In the Field

During the summers of 1964 and 1965, series of experiments were carried out to study the development of larval instars of P. lituratus on broom or gorse, with pods, and in the absence of pods. The insects were reared in celluloid cages of the fourth design (page 33). The results indicated that only the larval instars which were provided with pods (both of broom or of gorse) were able to complete their development to the adult stage. Thus, pods of host plants are essential for the growth of Piezodorus. The duration of development varied in different seasons, depending on temperature and food. In 1964 the duration of incubation and larval development of the experiment started on 1st July, was 73.2 days. The bugs were able to develop, both crowded, or in

isolation. When they were reared in isolation, the total period of development was 2 - 4 days longer than in the crowded ones.

b) In the Laboratory

The cages used were polystyrene boxes (see page 46). Rearing was carried out at 15, 20, 25 and 28°C. The insects were provided with twigs of broom with pods, or without pods. In each temperature the larval instars were reared both in crowded conditions, and in isolation. Only when provided with pods did bugs develop to adults, and the total period of development, including incubation, was 59 days at 20°C and 43 days at 28°C under crowded conditions. This period was 1 - 3 days longer in isolated bugs reared at 20 and 28°C.

5. Fecundity in Non-migrated P. lituratus

Piezodorus is a migratory pentatomoid. It leaves its breeding fields in August and September, and flies to the woodland during the warmer hours of the day. An experiment was set up, using the bugs which were reared from eggs to adults in the cages, and were kept within the same cages from August to May in 1965 and 1966. The mortality during autumn and winter was 73% and 81% respectively, in the two years. In 1966 three pairs of survivors were bred on broom. The bugs fed, copulated, and oviposited. The average fecundity for three females was 35.6 eggs per female. Thus Piezodorus is able to mature and oviposit without migration.

Picromerus bidens (Linnaeus)

1. The habitat.

The site chosen for the study of this predacious pentatomid is situated on the south-east of Silwood and is called the Heath (see page 19). Some collections and observation on it were also made in other localities in southern England.

Picromerus favours damp habitats with plenty of shrubs. It is found on river banks, margins of bogs, bushes growing on meadows, margins of woods and less frequently near to coniferous trees. Being predacious it appears to have no clearly defined habitat, but is generally found in sheltered, humid places. At Silwood Park and Cricket Hill in Yateley, it was more easily found in sunny days, searching for its prey amongst vegetation, often near the bases of bushes up to one metre and occasionally up to two metres in height.

2. Food.

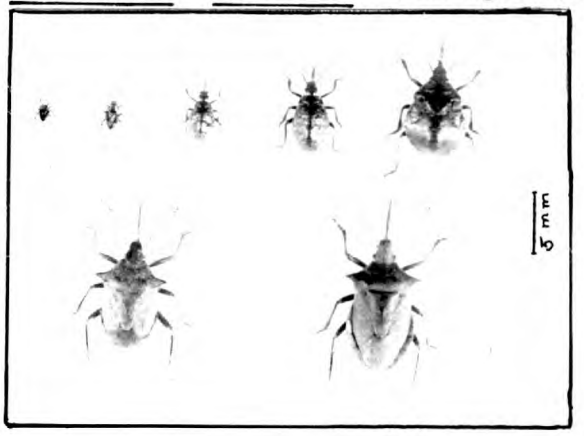
Picromerus is a common species of Amyotinae. Being a predator, it feeds on many species of insect larvae and to a lesser extent on insect pupae and adults. It is often found on plants which are attacked by leaf-eating larvae, particularly by Lepidoptera and Chrysomelidae.

Vast numbers of insect larvae have recorded as food of Picromerus. The earliest record is that of De Geer, who says that it feeds on the larvae of Hemerobiidae and of Chrysomelidae(in Butler, 1923).

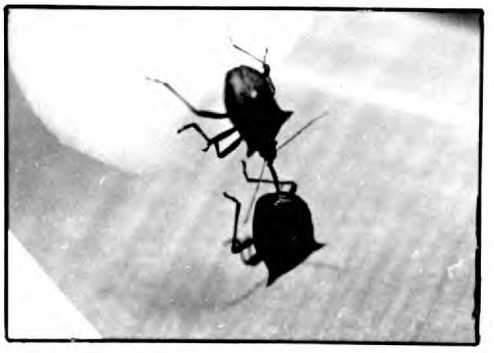
During the present work in and around Silwood Park, Picromerus was also observed, feeding on many species of lepidopterous larvae (mostly Pieridae, Geometridae and Noctuidae); Coleoptera (Chrysomelidae, Tenebrionidae); Diptera (Calliphoridae, Syrphidae). It was rarely seen feeding on Homoptera (Aphidae) and Heteroptera (Pentatomidae). One Picromerus at Silwood was found on broom, carrying an adult of Galeruca tenaceti L.(Chrysomelidae), its thick rostrum was inserted into the third abdominal segment of the beetle. It was also seen feeding on Leptophyes thelessine (Tettigoniidae, Orthoptera) (fig. 31). It continued sucking its prey for more than 59 hours. It was interesting to observe how the predator changed the piercing points on the body of the prey. The prey was held within an angle formed by the twigs and the front legs of predator. Every time it was pierced it was carried again towards the top of the twig. Small larvae of insects are frequently attacked but Picromerus will also attack some large larvae of Lepidoptera (see Schumacher, 1910 and Puchkov, 1961).

Photo: R.W. Ashford

Picromerus bidens feeding on its prey in the field.
Prey : Leptophyes thelessine (Tettigoniidae)



Larval instars and a pair of adults. Female (right)



Cannibalism

Feeding on Tenebrio molilor larva

Fig. 31.– PICROMERUS BIDENS (L.)

At Silwood the early instar of Picromerus appear in May and June, and aggregate in the first three instars. Search for prey begins from the second instar. The young larvae usually attack small prey. Groups formed by the second and third instars vary from two to more than fifty individuals; and the larvae attack and feed together. In the fourth and particularly in the fifth instar, they always occur individually among the grasses or bushes.

In 1964 and 1965 experimental breeding of adults, and rearing of larvae of Picromerus bidens in the field and in the laboratory, indicated that it is entirely carnivorous, but sometimes it will feed on the juices of plants as well. It was successfully bred on larvae of Tenebrio molitor L., Plodia interpunctella H., Pieris brassicae L. In each case they were also provided with water. Picromerus bred in the field were most often provided with larvae of Lepidoptera, and Coleoptera, collected locally. It occasionally preys upon some lepidopterous larvae four to six times longer than itself. In the laboratory it was observed to prey on the big larvae of Philosamia ricina (Saturniinae). It was rather difficult for Picromerus to get this large prey, but it succeeded in piercing it near the head end.

Cannibalistic behaviour was also observed several times in the laboratory and once in the field (fig. 31). On all occasions there were sufficient larvae of T. molitor in the breeding cages. Both sexes of the insect were found to suck each other through the 8th and 9th abdominal segments. Cannibalism was also observed in the larvae when they had no prey.

Picromerus bidens is widely distributed in Britain (Butler, 1923 and Southwood and Leston, 1959). It is also widely distributed throughout Europe up to 64° latitude in the North and possibly extends to Northern Africa in the South (Strawinski, 1927) to Ireland in the west and to Siberia in the east (Schumacher, 1910; Guld, 1919; Butler, 1923; Strawinski, 1927; Mayne and Breny, 1948; Dupuis, 1948 and Puchkov, 1961).

3. Description of Stages

Descriptions of adults and immature stages have been given by various authors (see Strawinski, 1927; Mayné and Breny, 1948). Fig. 31 shows different stages of Picromerus taken from the newly killed material collected in the field.

4. The time of Occurrence of Adults and their Larvae

The adults were collected mostly in late July and during August. The earliest records for collections of P. bidens are on 28.7.64, 21.7.65 and 16.7.66 at Silwood Park. In Yateley Picromerus were collected as early as 13.7.66, The bugs were found in smaller numbers in September and October. They were usually seen on broom, gorse, Rubus spp, grasses, and many other shrubs on warm and sunny days, when the temperature was above 15°C. All the adults died after a period of cool weather in autumn.

Eggs were laid from early August to November and overwintered until May. The first instar larvae appeared in May and June. The first records were on 13.5.64, 18.5.65 and 11.5.66 in the three seasons. The second and third instars were mainly collected in June , and that

of the last two instars during July and early August.

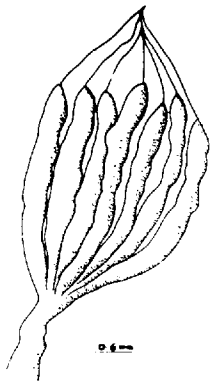
5. The Number of Adults and their Larval Instars

In the first three instars, the larvae usually aggregate and live close together in numbers varying from 3 to 62. This variation was due to much variability of the numbers of eggs in batches. In fourth and fifth instars they were collected mainly individually and in low numbers. The early stages were difficult to find as they live mostly on the dead leaves and branches on or near to the ground. The highest number of fourth and fifth instar larvae were 9 and 7 respectively, taken by 100 sweeps among the grasses near broom and Rubus sp on 13.8.65 at Silwood. The adults were more collected on broom bushes in the Heath and at Yateley. The maximum numbers taken by 100 beats were 13 and 11 in August of 1965 and 1966 respectively.

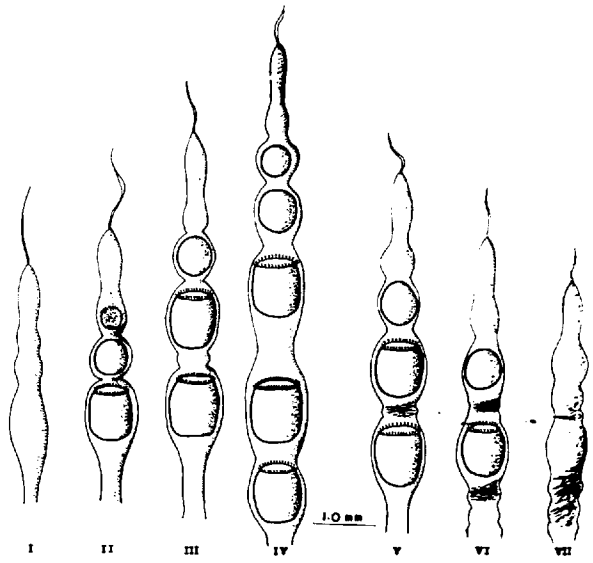
6. Reproductive Biology

Reproductive Organs: (fig. 32).

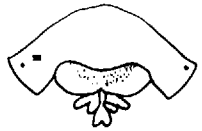
In the female these consist of a pair of ovaries, each with seven ovarioles which unite into the calyces of lateral oviducts and open into the common oviduct. The male reproductive system includes a pair of reddish, somewhat round testes which open into vesicula seminalis through the vasa deferentia. There are two pairs of rather short accessory glands which open into the vesicula seminalis. A pair of sharp and deep brown parameres are characteristic of the male of Picromerus (fig. 32).



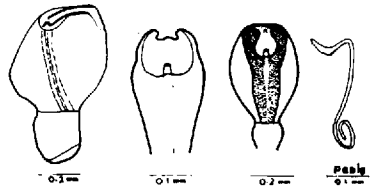
RIGHT OVARY AT MATURATION



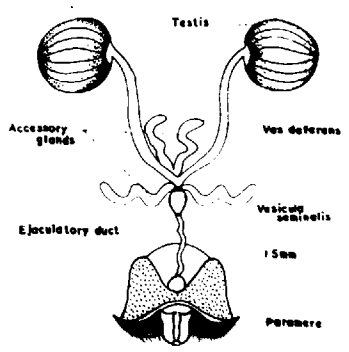
DIFFERENT STAGES OF OVARIAL DEVELOPMENT



UNDERSIDE OF TIP OF MALE ABDOMEN WHE PARAMERES ARE NOT SEEN



LATRAL, DORSAL AND VENTRAL ASPECTS OF AEDEAGUS



MALE REPRODUCTIVE ORGANS

UNDERSIDE OF TIP OF MALE ABDOMEN

DORSAL VIEW OF MALE GENITAL SEGMENTS

FIG.32.- PICROMERUS BIDENS (L.)

7. Sexual Maturation

a) The Effect of Flight and Walking on Maturation

The adults of the new generation of P. bidens were unable to mature sexually in late July and early August. Mating and oviposition always occurred about 15 - 20 days after the last moult. During this period the adults of both sexes were often seen walking and hunting their prey. In the laboratory the newly emerged adults collected in the field, or reared from eggs at 20, 25 and 28°C had a period of pre-maturation of 9 - 15 days at 27°C and 18 - 24 days at 20°C. Walking and feeding were essential for maturation of Picromerus. These were studied in a large number of insects during three seasons, both in the field and in the laboratory.

Mayné and Breny (1948) in Belgium and Strawinski (1927) in Poland, reported, that at mating, the bugs fly some distance. In southern England P. bidens did not fly but they dispersed from their original habitat some distance by walking. Among all observations during this work, only one male was seen to fly once, about 5m on a sunny day on .6.7.64 at the temperature of 26°C.

Thus, flight is not necessary for sexual maturation of P. bidens, whereas walking and feeding are essential.

b) Diapausing Period in Eggs of Picromerus bidens

In southern England the period of oviposition of P. bidens was from the middle of August to November in 1963 - 66. The eggs overwintered until May in a stage of diapause which terminated in early winter. The results of the field and the laboratory

experiments indicated that the eggs need to be subjected to low temperatures for about 30 days before development began. Without this, the eggs would not hatch. Thus, there is obligatory diapause which can be broken by low temperature.

In the laboratory the eggs of Picromerus were kept at 1 - 3°C in a refrigerator for about a month. Using this method, a continuous culture of P. bidens was established at Silwood Park.

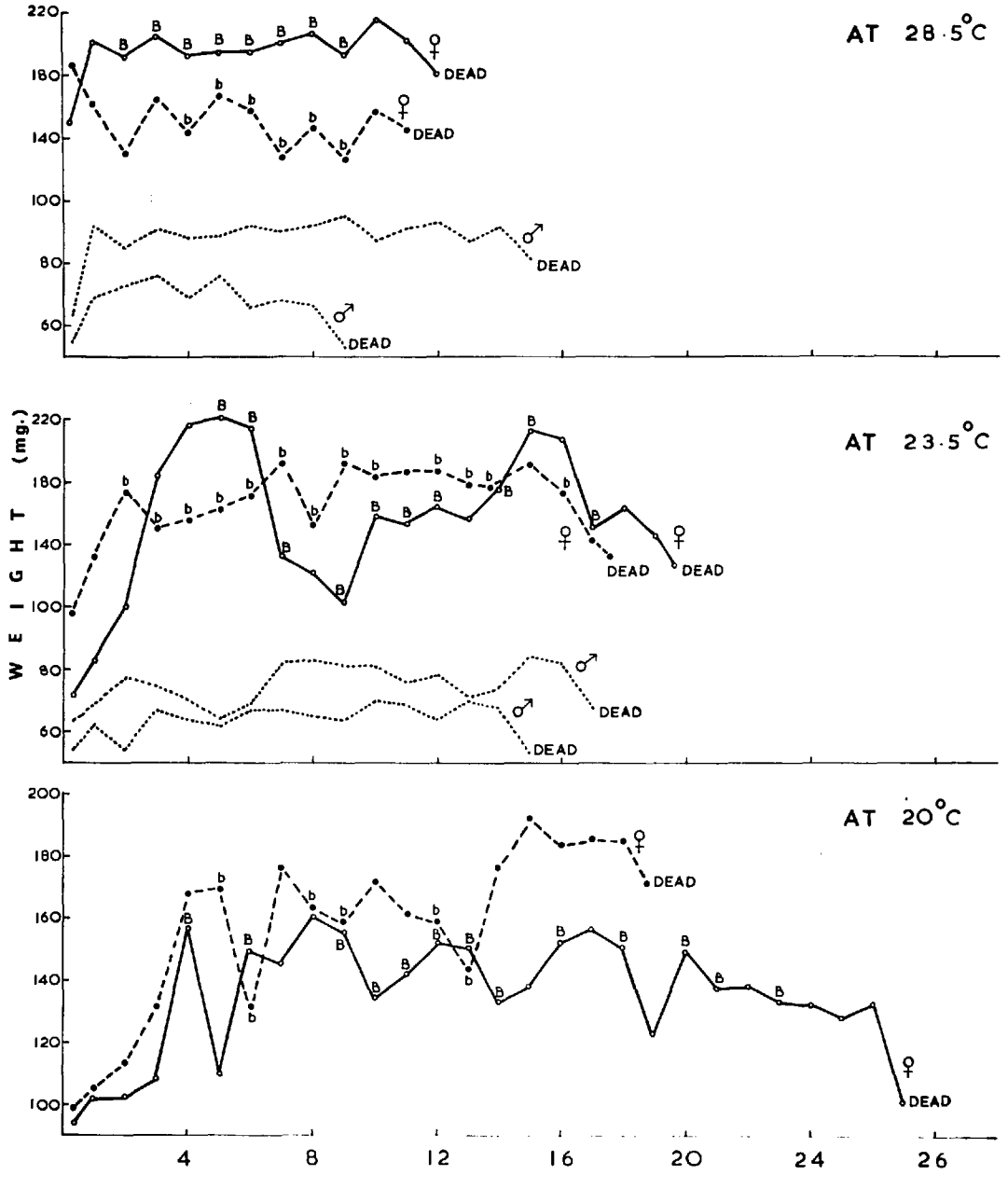
Mayné and Breny (1947) have studied the influence of climatic conditions on the hatching capacity of the eggs of P. bidens in Belgium and reported that low temperatures are indispensable for the embryonic development of the eggs.

c) The Changes in Weight on Maturation

In 1964 the changes of weight in both sexes of P. bidens bred in pairs in the laboratory were studied by weighing the bugs daily from their emergence to death. The mean weights of 20 males and of 20 females at emergence, the mean weight of 20 females before the first oviposition, and at death, are given in the following Table.

Table 21. Mean Changes in Weight in (mg) of Picromerus bidens in 1964

Pairs No. (replicates)	Temperature in °C	Weight at emergence		Weight of Female	
		Male	Female	Before first oviposition	Post-oviposition (at death)
20	20	59.1	108.9	162.6	120.4
20	23.5	58.1	100.0	153.7	122.3
20	28.5	56.2	105.0	163.2	126.3



Weeks After Emergence (Last week of July = week 1)

Fig.33- Changes in Weight of Picromerus bidens Throughout its Life at Different Temperature

As in the phytophagous bugs, in P. bidens there was an increase in weight during maturation of both sexes. The weight then fluctuated mostly with feeding and in the females with period of oviposition, and their death. The changes in weight of two pairs of Picromerus taken at random from stocks at different temperatures are also depicted in fig. 33.

d) Changes in the Reproductive Organs on Maturation

In the males, testis and the seminal vesicles develop and the accessory glands become swollen.

In the females, these changes are well marked by obvious development of ovarioles, which fill up the abdomen. Picromerus has a high fecundity and up to four eggs may develop in each ovariole before a batch is laid.

The ovariole development in Picromerus was studied in 1964 and 1965, by weekly dissections of 2 - 3 females collected in the field from late July to early October. The morphological changes in ovarioles during the life of females based on these dissections are shown in fig. 32. There are seven stages in which the IVth stage is very characteristic and in which the females have over 40 developed eggs simultaneously. At first stage there are three chambers in each ovariole within which the eggs gradually develop. The other stages are similar to those described in the other species.

8. Fecundity and Longevity of Picromerus bidens

A) Fecundity in the Field

During the last week of July 1964, 20 pairs of Picromerus were collected in the field. Each pair was introduced into a cage

made of celluloid cylinder of standard size and second design (see page 30 and fig. 4). The cages were placed on green branches of broom about one m from the ground surface. The bugs were provided with lepidopterous, coleopterous and dipterous larvae collected every 2 - 3 days by sweeping grasses, or beating the bushes on which Picromerus and its larvae occurred naturally.

During the period of breeding when it was difficult to collect the food larvae in the habitat, laboratory larvae of Tenebrio molitor L. and of Plodia interpunctella H. were provided. The experiment was started on 25th July 1964 and ended on the 25th November when the last female died. The counts of eggs laid were made every day during August and September but every other day in October and November. The reproductive behaviour and the death of bugs were also recorded. The period of pre-oviposition, oviposition and post-oviposition were examined in relation to temperature, and the average temperature during the life of males and females was also calculated. Out of 20 females, one failed to oviposit, for some unknown reason. This female lived for 84 days and copulated six times. At death it was dissected and the ovary had two developed eggs and one oocyte in each ovariole.

The details of fecundity, longevity, average temperature during the life of both sexes, and during the reproductive activities of the females, as well as the number of copulations throughout the life of females are given in Appendices XVII and XVIII The results are summarised in the two following Tables (22 and 23).

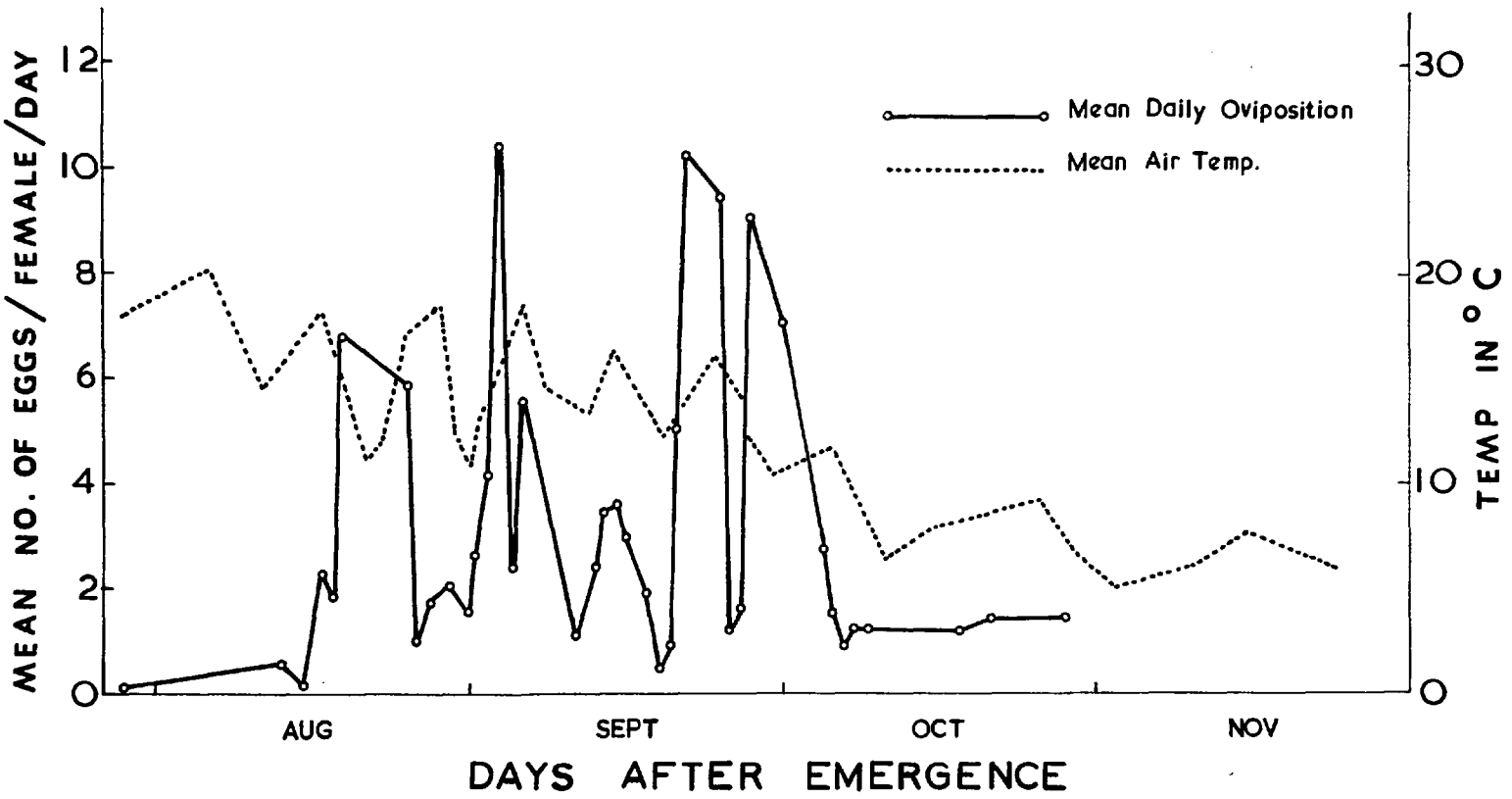


Fig.34.-The Fecundity of Picromerus bidens in the field in 1964

Table 22. Fecundity, Longeviry and Reproductive Behaviour of Picromerus bidens in the field in 1964

No of (replicates)	Mean temp °C	Longevity in days		Female Fecundity per female					No. of copulations observed
		Male	Female	Pre-ovip. period	Ovi-position period	Post-ovip. period	No. of egg batches	Total eggs	
Mean of 19	13.63	-	-	33.52	35.36	25.31	-	-	-
Mean of 20	-	83.45	93.7	-	-	-	5.50	129.15	3.45

Table 23. The Average daily Temperature during the Life of 20 pairs of Picromerus bidens in the Field in 1964

20 replicates	Male days °C	Female days °C		
		Pre-oviposition period	Oviposition period	Post-oviposition period
Average	13.21°	16.76°	13.54°	8.44°
Limits	10.9-16.0	14.4 - 17.5	10.7 - 15.8	5.7 - 12.1

In fig. 34 the mean no. of eggs per female per day is plotted against time. It can be seen that the period of oviposition of Picromerus in 1964 at Silwood Park started on the 14th August and lasted to the 24th October. The females laid most of their eggs in September. The peaks of oviposition are at the beginning and end of September. In the same figure the mean of daily temperature is also shown and it is clear that the fluctuations in the oviposition rate are related to temperature.

Table 23 and the curve of daily temperature further show that the females need high temperature for maturation, during the pre-oviposition period. In the field feeding and copulation were

observed 1 - 5 days beofre, or after, oviposition, but females which had mated only once, continued to oviposit. In all cases Picromerus copulated in sunny conditions and at temperatures above 15°C.

The maximum fecundity was 245, the eggs being laid in 10 batches of 5 to 47; the minimum fecundity was 8 eggs laid in a single batch by one female. The shape of one egg batch depended on the oviposition site, hexagonal batches were laid on leaves and batches of two rows on twigs.

B) Fecundity of Picromerus bidens in Relation to Temperature and Food in the Laboratory

As in other Pentatomoidea, almost nothing has been recorded on fecundity of P. bidens in Britain, but there are some reports from several European countries on this topic. Schumacher in Germany (1910 and 1911) observed that in an insectary a female of P. bidens is able to lay about 300 eggs during two months; Mayné and Breny reported that about 200 eggs were laid by one female in Belgium.

As it has been noted by the above authors and also by Strawinsky (1927) in Poland, the number of eggs per female is influenced by different conditions, food and temperature being the most important. In the present study, I have attempted to elucidate the effect of temperature on fecundity of P. bidens experimentally. Some data, such as the effect of food, crowding and mating on fecundity, have also been obtained.

a) The Effect of Temperature on Fecundity

In 1964, three experiments, each with 20 replicates, were carried out, using newly emerged adult Picromerus collected in the

field at Silwood Park. The bugs were kept in the polystyrene boxes designed for them. Food consisted of larvae of Plodia interpunctella, Tenebrio molitor and water. A pair of insects was kept in each replicate of each experiment (see page 45).

Breeding was carried out in a constant temperature room at 20°, 23.5° and 28.5°C and relative humidity of 75%. Both sexes were weighed daily throughout their lives. The weekly changes in weight of two females and males taken at radom from 23.5°, 28.5°C, and of two females from 20°C are shown in fig. 33.

At all temperatures the counts of eggs were made daily. Besides fecundity and changes in the weights, longevity of both sexes, and reproductive behaviour of Picromerus were also recorded. The details of these data are given in Appendices XIX, XX and XXI. The results are summarised in Table 24.

Fecundity, Longevity and Reproductive Behaviour of Picromerus bidens at Various Temperatures.

Table 24. Food - Tenebrio molitor, Plodia interpunctella and water

No. of pairs (replicates)	Temperature °C	Mean longevity in days		Fecundity per female				Mean No. of Copulations.
				No. of batches		Total No. of eggs per female		
		Male	Female	Limits	Mean	Limits	Mean	
20	20	93.1	122.45	1 - 16	8.6	36 - 407	217.0	5.4
20	23.5	90.0	90.7	3 - 24	12.55	43 - 497	257.0	3.3
20	28.5	72.85	72.75	1 - 19	7.6	6 - 314	108.8	2.6

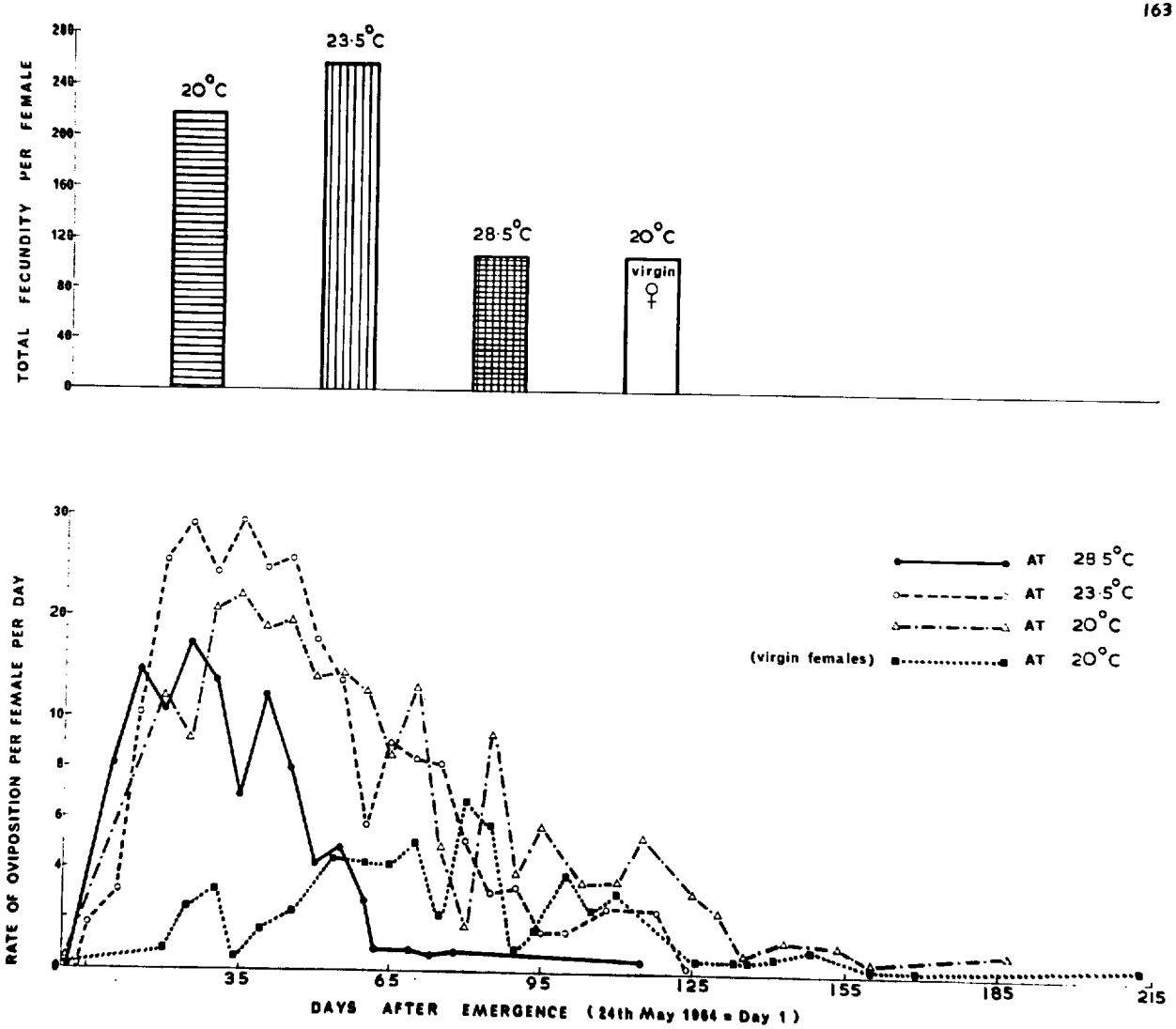


Fig.35.—COMPARISON OF THE FECUNDITY OF Picromerus bidens IN RELATION TO TEMPERATURE, FOOD-(Plodia interpunctella, Tenebrio molitor), LARVAE AND WATER

When the mean number of eggs per female per day is plotted against time for the whole oviposition period in the three experiments, a marked difference in the rate of egg laying is seen (fig. 35). In the same figure, the total fecundity per female at different temperatures is shown in histograms. The data clearly indicate that fecundity of P. bidens is much lower at high temperature. It is interesting to see that the maximum number of eggs was laid by females bred at 23.5°C. This indicates that Picromerus distribution is limited to cooler climates such as in southern England and in European countries. Thus, as stated by Strawinski (1927), report of P. bidens from African countries is doubtful.

Longevity decreased at high temperature, but, unexpectedly, the number of copulations also decreased at 28.5°C. For some unknown reason, at this temperature, females number 1 and 3 did not lay, although they lived for 43 and 58 days respectively (see Appendix XXI). At 20°C the mean number of copulations was higher than at 23.5° and 28.5°C. At all temperatures, before each egg laying, the females fed extensively, and mated. The mating period also varied at low and high temperatures. It was longer at 20°C with the maximym of 57 hours, and shorter at 28.5°C with a maximum of 33 hours. During copulation both sexes were commonly seen feeding.

In most females at different temperatures, laying was continuous throughout the period of oviposition. The number of eggs in the batches was usually higher at the beginning of oviposition. This

number in all batches varied between 2 to 73, but batches containing 25 to 35, laid in two to five rows attached together, were very common. The period between two ovipositions also differed, depending on temperature, feeding, copulation, the number of eggs per batch, and in the individual females. This period, however, was from two days to several weeks, with a tendency to a longer period towards the end of oviposition. The time taken to lay a batch of about 35 eggs, varied between one to 2.5 hours, this being usually shorter at high temperatures. The egg batches were laid in various shapes and on muslin and cardboard.

b) The Effect of Copulation on Fecundity

Similar to the phytophagous shieldbugs, the females of P. bidens were able to mature their eggs and to lay in the absence of males. The fecundity of virgin females, however, was much lower in all species. Thus, in order to find out the fecundity of unmated females of Picromerus, the following experiment was carried out in 1964:-

Eleven newly emerged females were collected in the field at Silwood, and were bred each in a polystyrene box similar to that used in the previous experiment at 20°C. Food and the other conditions of breeding were also similar, but no males were used. Although the longevity of virgin females was much longer than in those kept as pairs, their fecundity was greatly decreased. The period of maturation in non-mated females was also longer than in mated ones.

This experiment is summarised in Appendix XXII and condensed

in Table 25 . For comparison the data of females bred in pairs are also included.

Comparison of Fecundity and Longevity of Mated and Virgin Females of P. bidens bred at 20°C and 75% R.H. Food - Tenebrio and Plodia larvae and water

Table 25.

No. of females (replicates)	Mean No. of copulations	Mean Longevity of female in days	Fecundity per female		
			No. of batches	Limits of No. of eggs in batches	Average No. of eggs per ♀
20	5.4	122.45	8.6	13.7-43.9	217.0
11	No copulations	190.6	8.3	3.3-28.2	107.8

The mean of daily number of eggs per female, and the total fecundity per female, have been shown as a curve and a histogram (fig. 35). Comparison of the data indicates that the fecundity in virgin females is about a half of that of the mated ones, but their longevity is greater. The number of eggs per batch is also low in unmated females. Thus copulation increases fecundity in P. bidens.

c) Fecundity in P. bidens Reared from Eggs to Adults in the Laboratory

In 1965 an experiment was set up to study the fecundity and longevity of Picromerus reared in the laboratory at 20°C. The conditions of the experiment were similar to those of the previous one at 20°C with a pair of P. bidens in each replicate, but the insects were provided with T. molitor, Pieris brassicae larvae, and water.

Details of this experiment are given in Appendix XXIII. The results are summarised in the following Table.

Table 26. Fecundity, Longevity and Distribution of Oviposition Sites of Picromerus bidens (reared in the laboratory) at 20°C and 75% R.H. Food - Tenebrio molitor, Pieris brassicae larvae and water

No. of pairs (replicates)	Longevity in days		Fecundity per female			Oviposition sites. Eggs per female	
	Male	Female	No. of batches	Limits of No. of eggs in batches	Average eggs per ♀	Card-board	Muslin
5	70	82.4	5	12.2 - 36.6	103	91.4	11.6

Although no comparison can be made of this experiment with the preceding one at 20°C, because the food is not identical, it does provide an approximation of decrease in longevity and fecundity in Picromerus reared from eggs to adults in the laboratory. This was further confimmed in many other pairs which were provided with food identical to that mentioned earlier, The females in the present experiment laid most of their eggs on roof-shaped pieces of cardboard.

d) Fecundity in Crowded Picromerus bidens (reared in the laboratory)

Level of Crowding: 5 pairs in each replicate

Five pairs of Picromerus which were reared from eggs to adults in the laboratory at 20°C were bred in polystyrene cages used in the previous experiment. Breeding was carried out at 20°C and the insects were provided with T. molitor and P. interpunctella larvae and water. Sufficient food was given to all five replicates daily. The counts of eggs were made twice a day, in the morning and in the

evening. The bugs were observed feeding and showed more activity than those bred in pairs, even the Picromerus collected in the field.

The details of this experiment are given in Appendix XXIV. The results are summarised in the following Table.

Fecundity, longevity and Distribution of Oviposition Sites of Crowded Picromerus bidens (reared in the laboratory) at 20°C and 75% R.H. Food - Tenebrio molitor, Plodia interpunctella larvae and water.

Table 27. Level of Crowding: 5 pairs in each replicate

No. of replicates	Mean Longevity in days		Fecundity per 5 females		Total No. of eggs per female	Oviposition sites eggs per 5 females		
	Male	Female	No. of egg batches	No. of eggs		Cardboard	Muslin	Plastic
5	46.3	48.6	34.4	1121	224.3	917.8	152.6	51.2

When the data are compared with those obtained from bugs collected in the field and bred in pairs in the same conditions, it is seen that although longevity has decreased in the crowded conditions, fecundity per female has unexpectedly increased in crowded breeding. This is interesting because the bugs have been reared to adults in the laboratory. As in some other insects, this increase in crowded conditions may occur to a certain limit. More experiments should, however, be carried out on this topic, in order to reach any conclusions.

9. Rearing of Picromerus bidens

a) In Outdoor conditions

During three seasons Picromerus were bred both in isolation, or together, in the field. The period of development

from egg to adult took 72 to 87 days in different seasons. The nymphs started to feed from second instar on small larvae of different insects, as well as on leaves and twigs. The incubation period took 17 to 23 days. The period of nymphal instars was shorter at first and longest in the 5th instar, as in Piezodorus.

b) In the Laboratory

P. bidens was successfully bred to adults in the laboratory in isolation, crowded, and even in complete darkness, feeding on lepidopterous and coleopterous larvae and water. The incubation period was 18, 19 and 7 days at 20°, 25 and 30°C respectively. The period of development of nymphal instars was 55, 45 and 34 days at 20°, 25 and 30°C respectively. As a rule in Pentatomoidea duration of early instars is shorter than that of the late ones.

Three years rearing of Picromerus in the laboratory has shown that P. bidens is entirely carnivorous, but it also needs water for its development. Thus, in the field, it feeds on plants to suck water; therefore it cannot be considered as both phytophagous and carnivorous.

10. Number of Annual Generations of P. bidens

Picromerus is univoltine in southern England. During 1964-1966 only a few individual eggs hatched in September 1964 in high temperatures in the field between 22.8 and 4.9.64. Most of the larvae, however, died in the first and a few in the early second instars. All attempts to keep all the larval instars in the big cages placed on grass with broom and gorse, failed. The data therefore does not support Southwood and Leston's statement (1959) of secondary cycles of P. bidens involving overwintering as larvae in Britain.

AGGREGATION IN PENTATOMOIDEA

All species of shieldbugs studied aggregated in small numbers (from 2 to over 15) in the first three larval instars and also in the last instars of the phytophagous species. P. bidens however, was usually found individually in the fourth and fifth instars; this has also been mentioned by several other authors (see Groves, 1956). In the breeding cages in the field, and in the laboratory, when sufficient prey larvae were provided, Picromerus was also seen to aggregate in groups of up to 20 and over in all of its larval stages. It is therefore possible, that under natural conditions the larvae and adults of P. bidens are found individually because they disperse in search of prey.

Much has been written on gregarious behaviour of Aelia, Eurygaster, Palomena and Piezodorus in the literature in the field and particularly in their aestivation and hibernation sites (see Fedotov, 1947-60; Brown, 1962-66; Martin et al, 1960-64; Boselli, 1932; Puchkov, 1961 and 1965).

MIGRATION BEHAVIOUR IN PENTATOMOIDEA

Much has been written on the flight and migratory habits of some Pentatomoidea by several authors mentioned earlier. Recent investigations on genera Eurygaster and Aelia in the Middle East and south-west Russia have thrown more light on this topic (Zhukovskii, 1959; Brown, 1965).

During the present study, some observation on flight and migration of six species of Pentatomoidea belonging to six genera, were carried out in southern England, and particularly at Silwood Park. Simultaneously, the reproductive activities of all species were closely studied, with especial reference to the diapausing period of adults during aestivation and hibernation period of phytophagous species, since the state of the reproductive organs has been shown to be closely linked with migratory flight (Johnson, 1960-63).

Further, attempts were made to study these insects in different habitats in England, Scotland and Wales (as far as possible). This was carried out to see the effect of various habitats and also the effect of climate on flight. Conditions within the habitat and climatic conditions have been stated to be important in insect migration (Andrewartha and Birch, 1954; Southwood, 1962; Schneider, 1962; Brown, 1965; Johnson, 1966). The seasonal changes in population of A. acuminata and P. lituratus were also studied in a small selected habitat to see at which stage dispersal occurs.

All British Pentatomoidea studied are univoltine and after overwintering they migrate to their habitats in late April, May or

June. There they feed, mate, oviposit and multiply in June, July and August. The overwintered adults die after their reproductive activities. The adults of the new generation appear in August and September and feed extensively for about ten days on their food plants. Then Piezodorus and probably Palomena migrate a long distance, whereas Aelia (possibly also Neottiglossa) a short distance to the woodland near or far from their birth place. However they aestivate on or under leaves, on branches, and trunks of tall trees (both coniferous and deciduous) in late summer and the early part of autumn. Then, later, towards the end of October, they fly down and hibernate in a state of reproductive diapause under dead grasses and leaves, preferably in southern parts of woodland, but also under bushes of gorse, broom and Rubus sp, until the next spring.

In high temperatures (about 18°C for Piezodorus and 20°C for Aelia, Palomena and N. pusilla) in spring they leave their hibernation sites and migrate to their breeding habitat (not necessarily the same one as in the previous year), where they repeat their annual cycle.

The climatic conditions, and particularly temperature, rain, sun and wind, determine the flight and migration in the shieldbugs. For example, in June 1964, due to continuous rainfall and low temperature, the migration of most Pentatomoidea to their food plants was delayed for at least three weeks in southern England. During the whole of this period only a few overwintered bugs were found in their usual breeding sites. A. acuminata and possibly N. pusilla

were semi-migratory, whereas P. bidens appeared to be non-migratory.

In both sexes of all species, migration from the birthplace to aestivation sites in late summer, and their return in spring, always occurred, in females, when their reproductive organs were immature. Short flights within the habitat were often seen in both immature and fully mature individuals.

The take off before migration was repeatedly observed in Piezodorus and less frequently in Aelia on sunny and warm days in August and September, when the temperature was about 25°C. Before migration the bugs climbed to the top of twigs or grasses and exercised their wings repeatedly (opening the wings), then flew vertically or at an angle of 30 - 45° for about 5 - 20 metres and finally changed their direction and flew down wind towards a nearby, or a far off, woodland.

In all species of Pentatomoidea migration from birthplace occurred after the new adults fed for about 10 - 15 days mostly on pods and seeds.

Migration of Piezodorus was commonly observed in August and early September in high temperature (24 to 28°C) at Silwood, Yateley and the New Forest, from their birthplace mostly towards the northerly woodland to their aestivation sites on trees. There is also a report of a mass flight of P. lituratus coming in across the sea at Jersey during mid-April (Le Quesne's, 1946)

In all Pentatomoidea flight occurred on sunny and warm days between 10 a.m. to 7 p.m. Those Piezodorus and Aelia which emerged

in October were not usually able to migrate far from their habitats probably due to low temperature, rain, and possibly due to insufficient reserves in their bodies. These adults either remained within their birthplace or near to it; when temperatures rose some of them were seen to fly slowly about 3 - 5 metres above the ground to the surrounding trees. Piezodorus was able to fly in the laboratory at night at 22 - 25°C towards the fluorescent light, with or without legs and antennae, but no flight was ever seen in P. lituratus, Aelia or Eurygaster in darkness.

Conclusion:

1) Phytophagous Pentatomoidea studied, flew from their breeding places to aestivation sites and later to hibernation sites. From emergence to the end of the aestivation period both sexes have an obligate reproductive diapause and remain sexually immature.

2) In spring the shieldbugs leave their hibernation sites and some return to their original habitats.

3) In both leaving and immigration to the breeding sites, the climatic conditions, particularly temperature and light, and the physiological conditions of both sexes determine their dispersal.

4) Migratory Pentatomoidea (Aelia, Eurygaster and Piezodorus and probably the others) are also able to mature, feed, mate and oviposit without migration. Thus migratory habits are not always essential to sexual maturation.

5) The direction of migration of these pentatomoids out of their habitats is determined by wind. Both migration out of the breeding

sites, or immigration and flight within the habitats occur at high temperatures and in daylight.

6) In Johnson's (1966) classification of migratory insects into three groups, pentatomoids which aestivate and hibernate away from their breeding sites belong to Group III of this classification.

EFFECT OF SOME PARASITES AND PREDATORS ON PENTATOMOIDEA IN SOUTHERN ENGLAND

A) PARASITES

Three following groups of parasites attack these insects in southern England.

i) Hymenoptera of the family Scelionidae from the genera Asolcus and Telenomus. As controlling factors, these probably form the major impact on the population of Pentatomoidea. A detailed account of their biology, ecology and taxonomy is given in the second section of this thesis.

ii) Diptera of the family Tachinidae and subfamily Phasinae. From all adults of both sexes of Pentatomoidea dissected in different species only one female of A. acuminata collected at Yateley was parasitised by a dipterous larva of probably Phasinae.

iii) Nematode: In February 1964, the male genitalia of three newly dead Piezodorus collected in the field under grasses at Silwood, was heavily attacked by a sarcophagous Nematode identified by Dr. N. Hague as Panagrolainius rigidus SR(Thorne).

B) PREDATORS

Certain species of predators belonging to the Acarina,

Staphylinidae and Carabidae were occasionally seen to prey on immature and on the adults of Pentatomoidea. For instance, in September 1966 at Silwood, a beetle identified by Mr. B. R. Critchley as Carabus violaceaus (L.) entered a breeding cage of Picromerus (by chewing window muslin) and within 10 days killed seven P. bidens and nine batches of its eggs containing 183 eggs laid on broom. At Yateley immature and adults of Aelia and Piezodorus were rarely seen in spiders webs on gorse and in grasses. At the end of August 1965, in an area of gorse near Badger's Mount in Kent 7% and 3% of fourth and fifth instar larvae of P. lituratus were found dried out and obviously killed by some unknown predator.

Birds also are known to feed on pentatomoids but no observations were made on them in this work. An account of the fauna associated with Aelia and Eurygaster are given by Zwölfer (1930, 1932) Tischler (1937-38) Brown (1966).

SECTION 2

BIOLOGY AND TAXONOMY OF SOME PROCTOTRUPOIDEA (HYMENOPTERA - SCELIONIDAE)

The following species of scelionid egg parasites of Pentatomoidea are discussed in this section :-

Asolcus davatchii sp.n.

Asolcus nixo-martini sp.n.

Asolcus silwoodensis sp.n.

Asolcus waloffae sp.n.

Telenomus sokolovi Mayr

Telenomus truncatus Mayr

THE COMPLEX OF THE GENERA ASOLCUS AND TELENOMUS (HYMENOPTERA; PROCTOTRUPOIDEA; SCELIONIDAE), EGG PARASITE OF THE BRITISH SHIELDBUGS (HETEROPTERA ; PENTATOMOIDEA)

I. INTRODUCTION:

Among the entomophagous insects, the egg parasites of Pentatomoidea have been known for over a hundred years. These are minute wasps, less than two millimetres in size, parasitising the eggs of their hosts. Some species of these parasites have been found to be effective in controlling the populations of several serious pests such as Eurygaster integriceps Puton and Nezara viridula (Linnaeus).

In recent years several of these parasites have been extensively used against the above pests in the field, as means of biological control, mainly by large scale breeding and the release of adult parasites during the oviposition period of their hosts. Therefore, they are of high economic importance in agriculture, as well as of great biological interest.

These hymenopterous egg parasites are mainly of the family SCELIONIDAE but also include certain ENCYRTIDAE. They have a wide distribution throughout the world and a great deal is known about several of the species. Although the study of

these parasites was begun in the first half of the 19th century, their economical importance was realised only recently. During the past thirty years a great deal of effort has been made to find out suitable methods of application of these beneficial parasites in several countries. In spite of the knowledge of some aspects of the biology of several species of these parasites, and of their hosts, there is still a great deal to be discovered about them, in order to make the best use of them.

In the present work several of the fundamental problems in the study of Pentatomoidea and of their egg parasites have been elucidated. Altogether six species of Scelionidae of the genera Asolcus (= Microphanurus) and Telenomus previously unknown and new to Britain have been discovered. A new method of culturing them throughout the year on the eggs of Picromerus bidens L. has been established. Since the taxonomical position of some of these hardly determinable entomophagous insects based on morphological criteria was found to be uncertain, an attempt was made to find a reliable method for their indentification. Therefore, the biology , ecology,

morphology and the reproductive organs of six species were studied in as much detail as was possible.

In the light of this knowledge it was thought satisfactory to establish a new method of identification of these or similar closely related species.

The methods take into account both the morphology and biology of the species and the title proposed for them is "bio-morphological taxonomy".

Finally, a preliminary distribution map of the egg parasites and their hosts has been prepared to guide further research workers on this subject.

REVIEW OF LITERATURE

Studies on the egg-parasites of Pentatomoidea have been neglected in Britain in the past. This is probably because the British Pentatomoidea do not cause noticeable damage to crops and are of no economic importance as they are in many other countries. In the literature only a few remarks have been made on the British Scelionidae (telenomids), egg-parasites of the shieldbugs. The first record is that of Kirkaldy (in Butler, 1923), reporting that the eggs of Eurygaster maura L. were attacked by Telenomus sokolovi and Asolcus (Telenomus) semistriatus. Butler (1923) has mentioned that the eggs of Piezodorus lituratus (F.) are subjected to the attack of a minute hymenopterous parasite, a proctotrupoid of the genus Telenomus. Nixon (1939) in a redescription of the German specimens of Asolcus (Microphanurus) semistriatus Nees, says that he has examined a series of typical semistriatus which emerged from the eggs of Troilus luridus (F.) in Slough, Bucks, England, and which had been collected on birch by O. W. Richards on 8. 6. 1934. Richards (in Woodward, 1949) reports a batch of 14 pentatomid eggs which have been found to be probably T. luridus attacked by scelionid (telenomid) parasites; the parasites which emerged were 12 females and two males. These he identified as probably a species of Microphanurus.

In other countries, where the pentatomoids cause damage on crops, their parasites and particularly the Telenominae species have received considerable attention. The studies on the taxonomy of some species of these egg-parasites were started over a hundred years ago. Nees (1834) was apparently the first to describe A.(M.)semistriatus. Then Thomson (1861) and Mayr (1879 and 1908) have described or revised many species of these scelionids. Kieffer (1926) in his book on Scelionidae gives further information and descriptions and revisions of many species of Telenominae, particularly from Europe. Nixon (1935, 1939, and 1943) has described and partly revised some African, Asian and European (but not British) Telenominae that attack the eggs of the shieldbugs.

In recent years these telenomid parasites have received more attention, since the study of their biology has revealed that several species are effective natural enemies of their hosts and keep down the populations of the pentatomoid pests in nature. Masner(1958) studied some European species of telenomids and mentions the difficulties in identification of several of these minute parasites. In (1959) Rjachovskij and later Viktorov (1964) listed the Russian species of these parasites which were partly studied earlier by Vassiliev (1913) and by Rubtzov (1944). Alexandrov (1947 and 1949) listed seven species of Persian telenomids.

During the last ten years the heavy reduction of cereal crops in the Middle East countries caused by some Pentatomoidea, particularly of the genera Eurygaster and Aelia, has stimulated the Food and Agriculture Organization of the United Nations in organizing research work to determine a suitable method to save crops, especially wheat cultivation. Among the published papers by research workers in this organization on the taxonomy of the above mentioned scelionids, are those of Delucchi (1961). His investigations on the taxonomy of the Moroccan and the Middle East Asolcus species indicated the misidentification of several closely related species of Asolcus by several authors. He has apparently used, for the first time, several biological characters studied by Voegelé (in Delucchi, 1961) in the diagnosis of the closely allied species. His work has been supported by Vi torov (1964) and by Voegelé (1965).

There is fairly good information on the biological data on several species of Telenominae and particularly those of the genus Asolcus. Most of the information has been obtained from field work, in the hope of using the parasites in control of several Pentatomoidea, especially Eurygaster integriceps and Nezara viridula.

Vassiliev (1913) was probably the first to suggest the use of several species of scelionids parasites in controlling the population of E. integriceps in the south-west regions of the U.S.S.R. Morkryecki (1926) studied several species of these parasites and supported their use in biological control. Boselli (1932) investigated the effect of five species of telenomids in controlling the population of several shieldbugs, particularly Palomena prasina (L)which caused much damage to the Hazel nut crop in Sicily. He considered these natural enemies to be very effective and suggested further studies for their best use.

Kamal (1938) studied the biology and particularly the developmental stages of A. (M.) basalis Wollaston (= megacephalus Ashmead) in Egypt. This wasp parasitises the eggs of Nezara viridula which attacks the cotton crops there but also has a wide range diet. Tischler (1939) collected five species of telenomids that attacked the eggs of Eurygaster maura L., Aelia acuminata L., Palomena prasina, Dolycoris baccarum L. and Carpocoris pudicus Poda in Germany. In 1940, Kaussari (in Vodgdani 1954, Zomorrodi, 1959) and Alexandrov (1947 and 1949) observed about 90% parasitism in the eggs of E. integriceps in the region of Khar and Varamin, in Iran. Alexandrov, listed seven species of scelionids attacking the eggs of this pest and established the breeding of telenomid parasites and their application in the field in the regions of Varamin and Isfahan in Iran. Since 1949 the biological

control against E. integriceps has been used in Iran. Vodgdani (1954) and Zomorrodi (1959) have obtained some information on the biological control by using several species of Asolcus (Microphanurus) against their hosts, particularly A. (M.) semistriatus and A. vassiliev Mayr in Iran.

Talhouk (1961) studied the biology of A. semistriatus in relation to humidity and temperature. He gives a summary of the use of this Asolcus in control of E. integriceps in the Middle East countries. Wilson (1961) has investigated the reproductive behaviour in A. basalis (Woll.) bred on N. viridula in Australia. Puchkov (1961) in his book on Pentatomoidea gives some information on the egg parasites of the shieldbugs, particularly those occurring in the south-west regions of the U.S.S.R. Brown (1962), in his notes on the parasites of Pentatomoidae and Scutelleridae in the Middle East countries, has referred to the biology of six species of the parasites. He speaks of the use of Asolcus species in biological control in Iran.

Voegelé (1961, 1964 and 1965) studied the biology of the Moroccan species of Scelionidae and Encyrtidae. His biological investigations showed several interesting differences between the various species.

Martin and his colleagues (unpublished 1960, 1961, 1962 and 1963) in a series of 10 technical reports for F.A.O. have studied the biology, ecology and the methods of utilisation

of selected species of Telenominae in the field of biological control and of integrated control in Iran and particularly in the Isfahan regions.

Martin (unpublished, 1964) in his eleven reports investigated the efficacy of Asolcus semistriatus and A. grandis against the Sunn Pests in the Esfahan region. He stated that the use of these parasites in control of E. integriceps is successful when the number of the overwintered pest hosts is not more than three per square metre. He has also studied the biology and ecology of several other Asolcus and their possible use in integrated control of the shieldbugs.

Hidaka (1958) investigated the biology of Telenomus gifuensis Ashmead, which attacks the eggs of the black rice bug (Scotinophara lurida Burmeister) in Japan. Later Kiritani (1963) studied the parasitism in the eggs of Nezara viridula attacked by Asolcus mitsukurii Ashmead and Telenomus nakagawai Watanabe at Asso in Japan. They have proposed the possibility of biological control by these parasites against their hosts, which cause an important reduction of paddy crops in Japan.

Vi torov (1964) has studied the egg parasites of several pentatomids in the Saratov regions of south-west Russia especially the host preference of the parasites. He has indicated that the character of food specialization of several species of Asolcus is diagnostic of the species.

Cumber (1964) in studying two native species of Asolcus and A. basalis in New Zealand (the latter species had been introduced to New Zealand from the Australian stock (Cumber 1951)), says that these parasites have produced a biological balance of the troublesome N. viridula in New Zealand. He adds that A. basalis has established itself all over the country. He also discussed interspecific competition and the unsuccessful attempts to cross the different species of Asolcus. This was also mentioned by Safavi (1963) while studying several species of Asolcus, particularly A. grandis Thomson.

On further studies of the biology and morphology of A. basalis Voegelé (1965) found that the previously described species was in reality a complex of four closely allied species, three of which have not been previously described.

Hokyo and Kiritani (1966) studied the oviposition behaviour of A. mitsukurii and T. nakagawai in the Asso district of southern Japan. They have mentioned the behaviour differences in recognition of the egg masses, intra- and interspecific relationships of these two parasites, as well as the agressive behaviour of the females. These biological characters have also been noted in A. basalis by Wilson (1961), in A. grandis by Safavi (1963) and in A. basalis by Cumber (1964) Voegelé (1965).

Hokyo and Kiritani (1966), on further studies on the general bionomics of the two above mentioned telenomoids, report that A. mitsukurii is bisexual, polyphagous and prefers small host egg mass, whereas T. nakagawai is unisexual oligophagous and prefers large host egg mass.

MATERIALS, METHODS AND TECHNIQUES

A) Material for Investigations:

Four British *Asolcus* species and two *Telenomus* species were collected in the field in southern England. Most collections were made in Berkshire (Silwood Park), Hampshire (Yateley and the New Forest) and some in Surrey (Wisley Common) and in Kent (Badger's Mount).

Twenty-four *Asolcus* and three *Telenomus* species foreign to Britain were also studied for biological and morphological comparison. These specimens were received from the following research establishments:-
Plant Pests and Diseases Research Institute, Evin, Tehran; as well as the Department of Applied Entomology, Agricultural College, University of Tehran, Iran; Research Station, Wakayama Agricultural Experiment Station, Wakayama, Japan; Division d'Entomolgie, Station Central de Phytiatrie, Rabat, Morocco; Entomology Division, Department of Scientific and Industrial Research, Auckland, New Zealand; Institute of Animal Morphology, Academy of Science of USSR, Moscow, U.S.S.R. Two species of Middle East *Asolcus* and one *Oencyrtus* (Encyrtidae) were received from Division d'Entomologie, Institut Pasteur, Paris, France. Most of the African, Asian and European species of

these parasites were studied at the British Museum (Natural History) London.

For biological experiments on the closely related species the live parasites of all six British species, three Persian species including Asolcus semistriatus Ns (Delucchi), A. grandis Thom. (Delucchi) and A. vassilievi Mayr, as well as two Moroccan species of the first two Asolcus mentioned above were used. All the rest were studied from preserved specimens. The terminology of Richards (1956) has been followed for the morphological features.

B) Eggs of Pentatomoidea:

For studying the scelionids egg parasites of the shieldbugs it was necessary to collect and culture the gravid females of different species of Pentatomoidea in the laboratory and in the field. Apart from Eurygaster integriceps Puton which were supplied regularly from the Plant Pests and Diseases Research Institute, Evin, Tehran, Iran; all other phytophagous and carnivorous hosts used were collected in southern England, particularly at Silwood Park, Yateley, New Forest, Wisley Common and Kent (figs.3,36). At the beginning of this work in Summer 1963, about 1,000 eggs of E. integriceps were received from F.A.O. Sunn Pest Information and Documentation Centre, Pasteur Institute, Paris, France.

In order to obtain the eggs of shieldbugs, both sexes of E. integriceps, Aelia acuminata, Neottiglossa pusilla (G.), Dolycoris baccarum, E. maura, and Coreus marginatus (L.) were placed in rectangular polystyrene and cylindrical cellulose acetate cages of different sizes depending on the number of insects in culture. They were fed on grain or shoots of wheat (variety, common British wheat) and barley (variety, Proctor). Two roof-shaped pieces of cardboard were placed within the cages, with a sheet of fine muslin covering the bottom of the cage. These were usually used by the females as oviposition sites. Palomena prasina, and Piezodorus lituratus, were cultured in similar cages with fresh twigs of broom or gorse with buds or pods.

The predacious Picromerus bidens (L.) were bred in similarly designed cages of the above materials and were provided with lepidopterous and coleopterous larvae. These larvae were obtained from the laboratory, or were collected in the field.

The shieldbugs were cultured at different temperatures varying from 15° to 30°C, depending on the experiment, or, in the laboratory at a temperature of about 20° C, as well as in the field.

To ensure a permanent supply of the host throughout the year E. integriceps and P. bidens were nearly always in culture, whereas the other species were bred mainly during their oviposition period in nature.

These eggs were usually laid on roof-shaped pieces of cardboard and muslin when the diet consisted of grain of cereals and of pods and on leaves and stems when the bugs were fed on broom, gorse, wheat and barley. Egg batches were collected usually twice a day and were placed in small polystyrene, ventilated boxes designed for this purpose. These boxes were then placed in larger boxes of the same material made for keeping the eggs of these insects at 2 - 3°C in a refrigerator. The large boxes were also ventilated through holes, and covered with muslin, made on their sides. The floors of these boxes were covered with sand to a depth of 2 - 3 cm. This was dampened to produce a humidity of about 65 - 70% within the cages. Therefore the eggs were kept in this way from 4 to 7 months at low temperatures depending on the species of hosts and gradually used in various experiments on telenomid parasites obtained from the routine culture.

B) METHODS OF STUDYING THE PARASITES

a) Method of Collecting the Egg parasites in the field.

1. Beating method.

All six British telenomids were collected by this method. Usually a handful of branches of broom, gorse, stems of grasses, were shaken several times over a white cloth tray; the parasites were collected immediately in glass tubes of 1.5 X 10 cm or by an especial small pooter. The adult parasites were normally captured when the weather was warm during the oviposition period of their hosts. It was difficult to recognise these minute parasites among many other species of Hymenoptera of about the same size and colour on the tray. During the warm hours of the day, and particularly on sunny days, they were very active and most of them flew away rapidly. Therefore they had to be collected immediately.

To avoid losing any parasites when the temperature was higher than 20°C parts of these plants were placed in a sweeping net and shaken several times. After the branches were removed the open end of the net was tied to a small glass tube which was placed under a light. The parasites were soon attracted to the light and captured in the tube which was then plugged. The parasites were examined and sorted out later at a lower temperature.

2. Sweeping Method:

This method was used to collect the parasites on the grasses. A standard sweeping net was used. Usually after about ten sweeps the open end of the net was tied to one end of a test tube as described above. This method was successful during the warm hours of sunny days.

b) The Method of placing egg batches in the field and collecting them after a limited period of time.

This was a very successful method of collecting different species of telenomid parasites particularly the rarer species which were difficult to find by the other methods. A large number of Asolcus species, and to a lesser extent of Telenomus, were collected by this method in May, June and July 1964, 1965 and 1966 at Silwood Park and at Yateley.

Many batches of eggs were placed in the field on gorse, broom and grasses in the above mentioned areas and also at Common Garden and University garden in Southampton during March, April, September and October, but no egg batch was parasitised. In applying this method a large number of eggs of Pentatomoidea were needed in May, June, July and August. These were obtained by mass culturing of E. integriceps, A. acuminata, P. lituratus and P. bidens at high temperatures.

The eggs were usually collected within a few hours after oviposition and were stored at a temperature of about 3°C. The batches of eggs were pasted by melted bees wax on to the middle parts of 4 X 12 cm pieces of cardboard. These pieces of cardboard were hung on the branches and stems of grasses by bits of string. These batches contained a single batch of eggs from each one of the different host species. This was necessary since several species of parasites were found to be host specific. The cardboard pieces were usually fixed about 70 - 90 cm above the ground level hence not directly exposed to sunlight and rain; during the hot days some of the eggs were found to be shrivelled. In grass fields these pieces of cardboard were fixed about 20 - 40 cm above the ground; preferably dense patches and hence they were usually protected from exposure. They remained in the field for about 15 - 20 days. Unfortunately many were lost or damaged.

The cardboard pieces with the eggs were collected from the field after about 20 days, depending on the weather. They were then examined and separated into parasitised and unparasitised batches and placed separately in 2.5 X 5 cm polystyrene boxes designed for culturing the parasites. These boxes were kept at various required temperatures until the parasites emerged.

c) Collecting the naturally parasitised egg batches in the field.

At first many days were spent searching for the parasitised egg batches in the fields of various counties. After studies on the oviposition period, oviposition sites and the localities were completed in different fields, it was possible to collect about 100 parasitised egg batches of Piezodorus lituratus in one day during June and July. In July the majority of eggs of P. lituratus were parasitised by two species of Asolcus and two species of Telenomus. Therefore this method was found to be suitable for the study of the biology and ecology of hosts and their parasites.

d) Method of finding the adult egg-parasites in their aestivation and hibernation sites.

It was difficult to collect these parasites from about the end of August to May. These parasites aestivate in empty dried shells of pods of gorse, broom and particularly under the leaves of fruit trees in the shade. These usually were within a few miles' radius of the breeding sites. As the aestivation sites are abundant in the southern Thames Valley and as the parasites themselves are minute, they are extremely difficult to find.

Hibernation Sites (October to April)

Same Habitat at the time of Migration of Hosts and Parasites

(August and September)

Same Habitat at the time of Occurrence of the Hosts and Parasites
(June and July)

Fig.36. SEASONAL CHANGES IN THE HEATH AREA ; THE HABITAT IN WHICH ALL Pentatomoidea AND THEIR EGG PARASITES WERE COLLECTED

Many attempts made to collect them during Autumn and .inter in their hibernation sites resulted in little success. In January 1964 and April 1965 two females of A. silwoodensis were found within the cracks of oak and pine trees about 50 cm above the ground on Heathland in Silwood Park. In mid August 1965 at Queen's Bower in the New Forest 25 females and 8 males of the same Asolcus were collected in the empty shells of gorse pods; the parasites were in aggregations three to five inside the shells, which were in the shade, around the centre of the gorse bushes about 50 cm above the ground level. At the end of August 1965 two females of the above mentioned species of Asolcus were also collected from the empty pods of gorse at Badger's Mount, in Kent, the shells being about 90 cm above the ground. Several other females of T. truncatus and A. silwoodensis were collected in March and April under clumps of gorse which were sheltered under dead grass at Yateley and Silwood Park. These bushes were shaded partly by tall trees such as oak, beech or pine. A. davatchii and A. waloffae as well as Telenomus sokolovi were not found in their aestivation or hibernation sites. Therefore this method is unsuitable for finding these parasites. Figure 36 shows the seasonal changes in the Heath area at Silwood Park; the habitat in which all Pentatomoidea and their egg parasites were collected and studied throughout the three seasons.

C) DISSECTION, PREPARATION, PRESERVATION AND DRAWING OF ASOLCUS AND TELENOMUS spp.

1. Dissection:

All dissections were made under the high power of the binocular microscope. The light received was from a 60w bulb spot light. A 2.5 X 5 cm polystyrene box containing distilled water, the sides of which were fixed by xylene, was used as a heat filter. This was fixed firmly on to the cylinder in front of the bulb by a piece of wire 2 mm thick.

The dissections were mostly made on a solid watch glass using a fine pair of forceps and two fine needles designed for dissecting the very delicate internal organs. These needles were made from pieces of glass tube 6 mm in diameter and about 10 cm in length; a piece of tungsten wire 1.5 cm sharpened electrolytically in a sodium nitrite cell, was fixed at one end.

Different methods of dissection used were as follows:-

Method A. Dissecting of immature stages of the parasites

The parasitised eggs of Pentatomoidea were placed in a solid watch glass containing a few drops of 5% Ringer's solution. The eggs were usually dissected from

round the chorion using two pairs of fine forceps. The contents of the eggs were then gently separated using a fine curved needle, for the eggs or the larvae of the parasites. Later the chorions and the contents were removed by means of a fine pipette. The eggs and early larval instars of the parasites were usually difficult to find, whereas the last instar larvae or pupae were obvious.

Method B. Dissecting of the adult parasites.

The external and internal anatomy of Asolcus and Telenomus species were studied in detail, mainly for the purpose of comparative taxonomy. The study of the reproductive system was of especial interest since it has been neglected in the past; these organs are delicate and are easily damaged; thus a successful dissection requires considerable experience.

Among many solutions tried, Kahle's fluid was found to be suitable in hardening the internal tissue for a complete dissection. This fluid is made of the following components:-

Alcohol 95%	30 ml
Formalin 40%	10 ml
Acetic acid	2 ml
Aqua Dest.	60 ml

The live parasites were placed in this solution in a solid watch glass and were immediately killed. The watch glass was then covered for about 10 minutes allowing the fluid to enter the body after which the dissection was carried out using the two fine curved needles.

2. Preparation of specimens.

a) Preparation of newly killed parasites:

The parasites were dissected as described above. The genitalia, antennae, legs, wings and mandibles were removed and placed in a minute quantity of Hoyer's mountant on a glass slide. It was then left covered in a petri dish for 10 minutes. This was found to be useful in holding separate parts, since the immediate preparation resulted in change in shape. The slide was checked again and a drop of Hoyer's added on top of the tissue and then a coverslip with a bit of Hoyer's mount on its side was placed on top. Hoyer's solution was found to be the best glue for mounting and preparing these specimens. It dries gently and enables preparation of the specimens in any form needed. On the other hand, it is water soluble (Beirre, 1955) and an elaborate dehydration procedure is necessary before mounting. It contains chloral hydrate which is the clearing agent. The specimens prepared in Hoyer's solution were kept permanently after being treated at 30°C for about fifteen days.

b) Preparation of dried specimens:

The dried specimens were prepared in the following way:

1) The parasite was placed in a solid watch glass containing 7% potassium hydroxide. The watch glass was covered and placed under a 40w bulb. The watch glass was heated for about 15 minutes and was then removed and allowed to cool. This period was found to be the best to soften and preserve the colour of different structures.

2) The parasite was removed from the potassium hydroxide and placed in another solid watch glass containing Kahle's fluid and dissected using two fine dissecting needles. Any structures needed were separated and removed to a third solid watch glass containing Kahle's fluid for about five minutes after which it was ready for staining.

3) The structures e.g. the genitalia were removed on to a glass slide and were fixed with Hoyer's mountant before they were allowed to dry slightly for 10 minutes in a covered petri dish and mounted as before.

3. Preserving the specimens:

Method A. Preserving of adults in fluid.

Both sexes of all Asolcus and Telenomus species were preserved separately in Kahle's fluid in specimen tubes of 2 X 3 cm with plastic covers. A full detail of the species e.g. the name of species, the host and locality were written on pieces of Bristol cardboard and were included.

Method B. Mounting of parasites on Bristol board.

The adult parasites were mounted on pieces of triangular or rectangular Bristol board, a triangular piece being used for a single male or female. The parasites were killed with ethyl acetate and mounted with Gloy. The rectangular pieces were used to stick two pairs of parasites in different positions.

Method C.

All the selected slides prepared for genitalia, antennae, legs, wings and mandibles were placed in an oven for 15 days at 30°C before being stored.

4. Drawing:

Most drawings were of parasites newly killed in Kahle's fluid. The eggs and some larvae were also drawn from live specimens. Drawings were made under the high power binocular microscope which held a squared eyepiece.

D) TECHNIQUES OF REARING ASOLCUS AND TELENOMUS spp.

Introduction:

The rearing egg-parasites of Pentatomoidea and of handling them in the experimental work was a major problem at the beginning of this investigation, both in the laboratory and in the field.

The rearing of these parasites, since the beginning of the late nineteenth century until the present time, has been carried out in test tubes covered by cotton wool. Many biological studies have been carried out on telenomids in such test tubes. This technique was recorded by Vassiliev (1913). Alexandrov (1947 and 1949) established a technique of rearing several Asolcus species in wooden cages with glass lids, containing two test tubes with water, the open ends being covered with cotton wool. This method was later modified for field rearing by using cardboard boxes one side of which was covered with transparent cellophane (Zomorrodi 1959).

In recent work transparent plastic boxes have been used by Voegelé (1961), Remaudière and Martin (unpublished). Although these techniques are still in use, particularly the rearing in test tubes, which is easy, the parasites, however,

survive for only a short period; furthermore the handling of these parasites in test tubes was also found impracticable since they are active at laboratory temperatures and are often lost. Therefore a new technique was evolved and is described below:-

REARING OF PARASITES IN THE LABORATORY

Round or rectangular boxes of transparent polystyrene, varying in size, and 1 - 2 mm thick, were used as cages in rearing the egg-parasites of Pentatomoidea. The following were found to be satisfactory:-

Design No. 1 Small rearing boxes.

Round polystyrene boxes were 2.5 X 5 cm (fig. 37) and one mm thick. Holes of different diameters were bored, two on the lid and one on the side. The hole in the centre of the lid was 1.3 cm in diameter and was covered with fine muslin. The hole on the side was about one cm in diameter, made close to the base of the box. A specimen tube of 8 mm in diameter and 5 cm in length containing water or a solution of honey was held horizontally in this hole. This tube was usually inserted half-way into the box. The humidity produced within the rearing box was about 75% and the parasites survived actively for a longer period than in the test tubes.

1 m
scale

---waterproof polystyrene roof

---wooden door

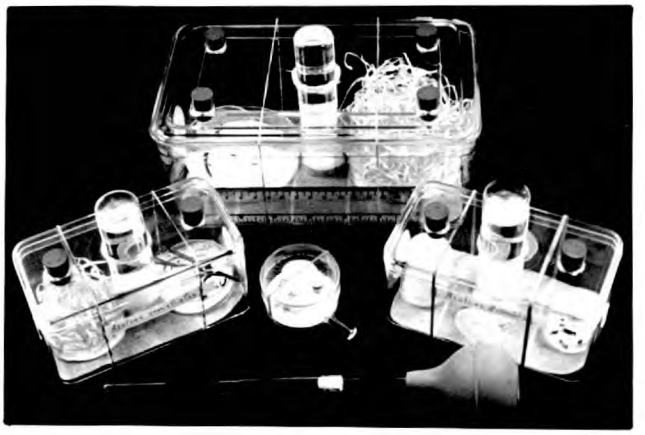
--muslin tunnel
for entrance

Large cage

Small cage with
celluloid cages within

WOODEN AND CELLULOID FIELD CAGES

Small cages
closed and open



Laboratory cages and pooter

Fig. 37. REARING CAGES FOR EGG PARASITES

The third hole was 18 mm in diameter, made in the lid between the ventilation hole and the side of the lid. This was used to introduce or to remove the parasites and egg batches, or for providing the food; it was usually covered with a cork stopper. Different foods such as honey, honey-dew, pollen and diluted honey or sugar were used, depending on the experiment. A very minute quantity of honey was rubbed on small pieces of wood wool and this prevented the parasites from sticking. Food and water were renewed every 7 to 8 days.

The bottom of each box was covered with filter paper. Three to four pieces of wood wool were also introduced and these were found to be useful as resting places for the parasites. The lid of the box was finally secured by a rubber band.

This was found to be a practical and a suitable rearing technique for a single pair, or up to 10 parasites kept at various temperatures. The parasites survived two to four months in these boxes at a temperature of about 20°C.

A U-shaped glass tube of 7 cm length was also used instead of the specimen tube. The shorter end of this tube was plugged with cotton wool and introduced into the box (fig. 37). This opening in the box was made air-tight.

Water and food solution were introduced through the other end of the tube which was usually plugged with cotton wool. However specimen tubes were found to be more convenient.

Design No. 2 Middle sized rearing boxes.

Round polystyrene boxes (fig. 38) of 10.5 cm in diameter with slanting sides of 4.5 cm high were used as rearing boxes for about 50 parasites in each. Although similar to the first type, this box had several modifications. The specimen tube used to supply water was 1.2 cm wide and was held horizontally midway on one side. The plug on the lid was about 5 mm and fitted closely on to three small studs placed outaide the top of this box. In the middle of the lid was a ventilation hole of 2 cm in diameter covered by fine muslin. Two holes of about 7 mm diameter were made opposite to each other about midway on the side and these were used for introducing parasites, food, egg-batches or wood wool, and were usually closed by a cork when not in use. The floor of the cage was covered with white filter paper. This was useful since the parasites tended to move under the filter paper when the illumination was more than that needed. About 5 pieces of 8 - 10 cm wood wool were used as supports for walking. The lid was fixed firmly with a rubber band. The food and water were renewed weekly.

The above mentioned rearing cage was found to be very practical in rearing the parasites and it was also cheaper as it was made of polystyrene.

Design No. 3 Large rearing boxes.

Rectangular polystyrene boxes of 8 X 14 X 6 cm of 2 mm thickness were used as rearing cages (fig. 37). About 100 parasites could be reared in them. They were specially designed for keeping the egg-parasites alive for long periods.

Three holes were bored on the lid, a large one of 3 cm in diameter was in the centre and two of 1.5 cm diameter were made on either side of the central one. A tube of 2.5 cm diameter covered by a hollow polythene bung served as a humidity controlling chamber. Two holes were bored on the centre of this bung; the outer one being 1.5 cm in diameter and the inner 7 mm diameter. The large opening was covered with cotton wool which partly filled up the space within the bung and the remaining part served as a source of the liquid necessary for the parasites. The glass tube was filled with water and inverted over the large hole made on the lid. As the inner hole on the bung was smaller than the outer one, pressure within this tube prevented the liquid from falling into the

box. As the plug was always moist the insects were able to lick the fluid when necessary. This was an important part of this design, since excess water or food solution could cause higher humidity and the sticking of the parasites.

Three holes each of 1.5 cm diameter, bored on the two narrow sides and one broad side were covered with fine muslin. The floor of the box was covered by a sheet of muslin on which the parasites could walk more freely. Two polystyrene lids of boxes used in design one, placed on either side of the humidity chamber, were fixed by a piece of bees wax on the muslin which covered the floor. This prevented these from sliding on the floor of the box and thereby causing any damage to the parasites. The lids could be removed frequently for cleaning. They were lined with white filter paper; one was used for placing batches of eggs and one or two pieces of wood wool brushed or dabbed with honey. The other lid was used to place a clump of wood wool or a rolled cylinder of muslin to provide a resting place for the parasites. Two holes on the top of the lid were used to introduce, or remove, the parasites, the food, batches of eggs and wood wool. These were normally closed by rubber bungs. The lid was secured by two rubber bands. The material within the rearing boxes was changed

every month and the boxes washed with Stergene and warm water to prevent the growth of fungi. In several experiments, 0.25 percent Nipagin fungicide solution was also used when the tube containing water was kept in the breeding room for more than a month.

These rearing boxes were useful in keeping the parasites for a longer period, for the conditions provided were sufficient to keep the parasites active for a period of about two to five months at 20°C. The relative humidity was about 75% and this remained almost constant for at least 25 days. The wood wool containing honey was usually sufficient for one week.

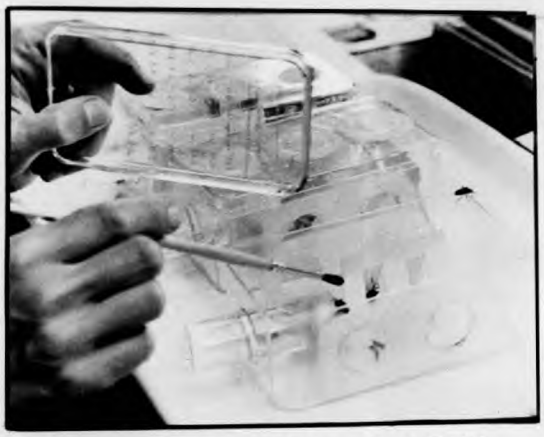
These boxes were tried out for rearing other species of parasites of different families such as Chalcididae, Encyrtidae, Trichogrammatidae, Mymaridae (with very fine ventilation muslin) and Aphelininae and were found to be suitable. Therefore they could be used in larger scale rearing of some other hymenopterous parasites.

Design No. 4 Mass rearing boxes.

This design was similar to the previously described boxes but with several modifications.

Rectangular polystyrene of 13 X 22 X 9 cm was used (fig. 37). Four holes were bored, one at each

Fig.38. REARING CAGES FOR PENTATOMOIDEA AND THEIR EGG PARASITES IN THE LABORATORY



Cage for Picromerus, a suitable host for most egg parasites

Cage for Piezodorus with gorse

Photo: J. wilson

Cages for Scelionid Parasites showing the use of a Special Pooter for handling the egg parasites

corner of the lid, to introduce or to remove the material within the cage. Two holes of 2 cm diameter were bored on the narrow sides of the box and covered with fine muslin. Two lids of 9.0 cm diameter petri dishes and a small lid of 3.5 cm were placed on the floor; the smaller one being filled with cotton wool. The latter was placed vertically beneath the humidity chamber and this served to collect any liquid that fell. The amounts of wood wool and the food provided were also increased.

These boxes were suitable for mass rearing of parasites, usually about 1,000. The parasites were kept for a longer period, lasting from three to six months. The boxes were also used for storing the parasites in the refrigerator at a temperature of 2 - 3°C. This provided laboratory stock of living parasites throughout the year that could be used in different experiments or in routine rearing.

The Design of a special pooter:-

It was very necessary to design an apparatus for safe handling of these minute wasps. Among the different designs the following pooter was found to be the

most satisfactory (figs. 37 and 38).

Two glass tubes of 7 cm and 8.5 cm respectively were joined to each other by means of a 8 cm long transparent flexible polythene tubing about 1.5 mm thickness. The ends of the glass tubes were made smooth to prevent any injury to the insects. One end of the 7 cm tube was inserted into a rubber bulb, a double sheet of fine muslin covered the other end of this tube, this being fixed on to the polythene tube which prevented the insects from being sucked into the rubber bulb. The flexible tube on the pooter was very useful for collecting insects that strayed on to the corners of the box.

FIELD REARING CAGES

Design No. 1:-

These cages were 20 to 25 cm in length and 8 cm in diameter cylinders of cellulose acetate which was 195 - 400 microns thick. Six circular windows, each 4 cm in diameter were made and covered with muslin. Two holes each 1.5 cm in diameter and 10 cm away from each end of the cylinder were made and plugged with rubber bungs. One end of this cylinder was covered by fine muslin and the other end was joined to a cylinder of muslin 10 cm in length and 8.5 cm in diameter. The holes in the cylinder served for the introduction or removal of the parasites, egg masses and the food. The open ends of these cages were placed on a suitable broom or gorse bush enclosing a few ends of twigs, the muslin cylinder being tied securely round the twigs. The parasites usually fed on honey dew provided by a few aphids, mainly Acyrthosiphon spp., on broom or gorse introduced into the cages.

These cages were usually placed within larger rectangular cages. The latter consisted of a wooden frame 1.30 m X 0.9 m X 1.40 m covered with fine muslin. A rain-proof cover made from a wooden frame 1 m X 1.40 m with a wire mesh covered by thick polythene material was placed at an angle over this cage. two such cages were placed on broom and gorse and one on grass (fig. 37).

Design No. 2 Special large cage:

This was a field cage of 1.2 m X 1.3 m X 2.0 m made from a wooden frame covered on the side and on the top by wire mesh of 2 X 2 cm (fig. 37); on one side was a fitting door of 1.35 m X 0.6 m. The cage within was covered with fine muslin which was fixed on to the wooden frame by means of a 2 cm made wire band. A tunnel 0.60 m in diameter and 1.5 m length made of fine muslin was tied to the entrance door of the cage. This was usually tied up when not in use. The floor of the cage was sunk on the sides, being covered with earth; the ends of muslin being kept down with the earth. A waterproof cover was placed on the top of the cage as before. The cage was secured to the ground by means of guy-wires of galvanised iron. These wires were attached to four screw-eyes on the top of the cage and were held taut by wooden pegs driven into the ground. The door of the cage faced north, since the parasites were mostly attracted to the other sides particularly during sunny warm days.

During May, June and July 1965 a large number of the six British telenomids spp. were released within the cage and the egg masses of the different hosts were also placed regularly on the twigs of plants for rearing the parasites and

thus enabling one to follow their life cycles in an approximately natural environment.

Many aspects of the biology, ecology and behaviour of the parasites were studied by regular observations made at least twice a week throughout the year.

THE TAXONOMY OF EGG PARASITE COMPLEX OF BRITISH PENTATOMOIDEA (HYMENOPTERA, PROCTOTRUPOIDEA, SCELIONIDAE) SUBFAMILY TELENOMINAE.

Six species of egg parasite of Pentatomoidea of the family Scelionidae were collected in southern England. They comprise four species of Asolcus and two of Telenomus.

The identification of these parasites is based on a comparison of Asolcus species in the British Museum; it is also based on a study of the biomorphology of the European, Mediterranean and the N. Eastern spp.

The study of males was also found to be necessary, particularly in the closely related species. Although the male genitalia were sometimes found to give good diagnostic characters, they appeared to be rather similar in the closely related species. The size of the adult did not appear to be very important, since this was found to be variable, especially in the polyphagous species (fig. 50).

Colouration was variable in the antennae and, to a much lesser extent, in the legs of some individuals within the species of certain Asolcus and Telenomus bred under different conditions and on various hosts in the laboratory. However,

it was almost constant and a very useful character in several other species.

Two Asolcus species were found to be specific to only two or three hosts, while others were bred from the eggs of more than 10 Pentatomoidea and two others also on one species of Coreidae.

All attempts to cross these parasites, especially closely related species, were unsuccessful. The females mated once and the progeny was of both sexes; unmated females always produced males only.

Biological data together with the morphological differences between six British and more than 20 non-British telenomids provide the basis for the keys given below.

Holotype females and allotypes of the new species and 20 pairs of each of the six British species as well as 10 pairs of Asolcus semistriatus Ns (Delucchi) and A. grandis Thom. (Delucchi), have been deposited in the British Museum (Natural History), London; ten pairs of paratypes (females and males) of the new species and all other species discussed in this work are in the Plant Pests and Diseases Research Institute, Evin, Tehran (Iran) and the Author's collection.

I. Asolcus NAKAGAWA (=Microphanurus KIEFFER, 1926)

The six species of Asolcus dealt with in this work have the following generic character in common:-

Body stout (fig. 39). Frons rugose or punctate in greater part. Eyes bare, or with very few minute scattered hairs. The last six antennal segments of female forming a club. First segment of male flagellum larger than pedicel; segments 6 - 11 subequal. Mandibles tridentate and rather thick. Mesoscutum rugose. Parapsidal furrows feebly indicated or absent. Scutellum finely sculptured or almost smooth. Abdomen nearly as long as wide. The anterior part of the second tergite striated; these striae usually extending beyond middle of the sclerite.

Key to species

1 Legs brownish-yellow to reddish-yellow in both sexes. Parapsidal furrows very feebly indicated (even under magnifications of X 125). Head distinctly wider than thorax. Antennae of male usually brownish-yellow in greater part.....2

\- Femora always black in both sexes. Parapsidal furrows absent. Head not distinctly wider than thorax;

seen from in front striated in greater part (fig. 49).
Antennae of male black or deep brownish.....3

2 Mesoscutum and scutellum finely rugose. Head rather concave seen from above (fig. 44). Antennae of female always black. Club normal. Fore wings hyaline; its length and that of stigmalis rather short.....A. waloffae sp.n.

- Mesoscutum rugose with longitudinal elements. scutellum weakly rugose, becoming smooth and shiny in the middle. Segments 1 - 4 of antennae in the female brownish-yellow. Club feebly stout (fig. 42). Fore wing hyaline; its length and that of stigmalis of normal length.....
.....A. davatchii sp.n.

3 All tibiae almost black in both species. Wings feebly darkened, venation dark or brown; stigmalis and postmarginalis slightly longer (fig. 48). Seen from above, head feebly convex (fig. 49). Antennae of male always black; (segments 6 - 11 square in line out).....4

- At least front tibiae always brownish-yellow in both sexes. Wings hyaline, venation faintly brown; stigmalis and postmarginalis slightly shorter (normal for the genus)

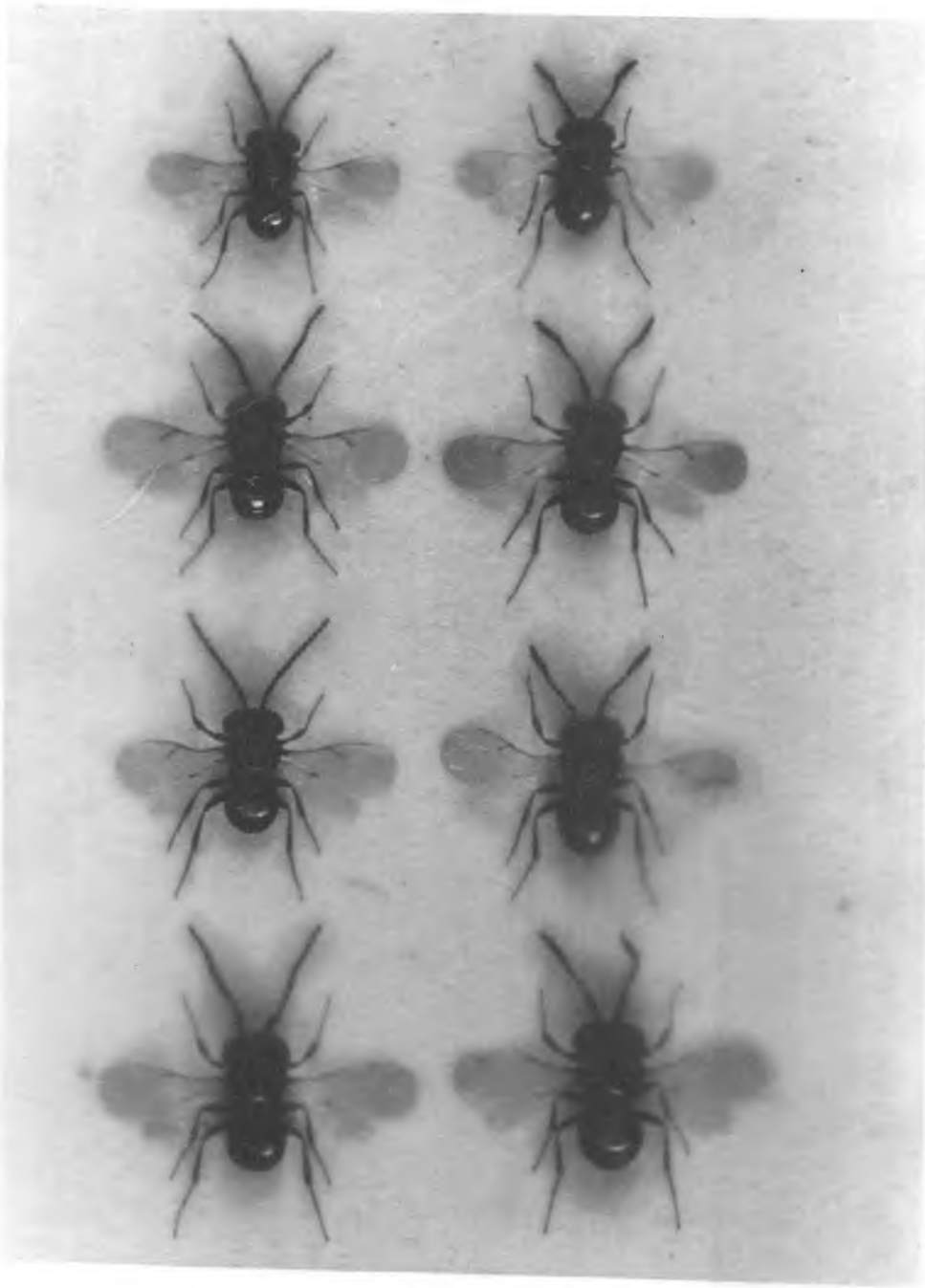


Fig.39

Four pairs of British Asolcus species (females on the right) bred from their pentatomid host eggs as shown below :

1) Asolcus waloffae sp.n. ; bred from Aelia acuminata (L.)

2) Asolcus nixo-martini sp.n. ; bred from Piezodorus lituratus.

3) Asolcus silwoodensis sp.n. ; bred from Piezodorus lituratus (F.)

4) Asolcus davatchii sp.n. ; bred from Palomena prasina (L.)

(Scale : Female of A. waloffae 1.0 mm in length)

(fig. 48). Seen from above, head feebly concave (fig. 49). Antennae of male brownish; (length of segments 6 - 11 of male longer than wide or subequal.....5

4 First flagellar segment of male twice as long as pedicel and 1.5 times longer than the second segment (fig. 47); rugosity of head strong, particularly on frons; distance between the lateral ocelli and eyes about half the diameter of an ocellus. Veins rather thick; stigmalis less than half postmarginalis. Male genitalia longer than in the related species (fig. 51). Tarsi blackish or deep brown in both sexes.....A. silwoodensis sp.n.

- First flagellar segment 1.5 times as long as pedicel but less than 1.5 times as long as the second segment (fig. 47); rugosity of head fine and becoming almost smooth around the frontal line. The distance between the lateral ocelli and eyes about equal to diameter of an ocellus. Stigmalis and postmarginalis rather thin; the former about half as long as postmarginalis. Male genitalia short and similar to that of A. semistriatus (figs. 48, 51). Tarsi brownish or brownish-yellow in both sexes..... A. grandis Thomson

5 All tibiae and tarsi brownish-yellow in both sexes. Head weakly concave (fig. 49). Segments 6 - 11 of male antennae subequal; (fig. 47). Stigmalis about half as long as postmarginalis..... A. semistriatus Nees

- At least middle and hind tibiae almost black in both sexes. Head somewhat concave (fig. 49). Segments 6 - 11 of male antennae longer than wide. Stigmalis less than half as long as postmarginalis. Male genitalia different in size and form, from that of related species (fig. 51)..... A. nixo-martini . sp.n.

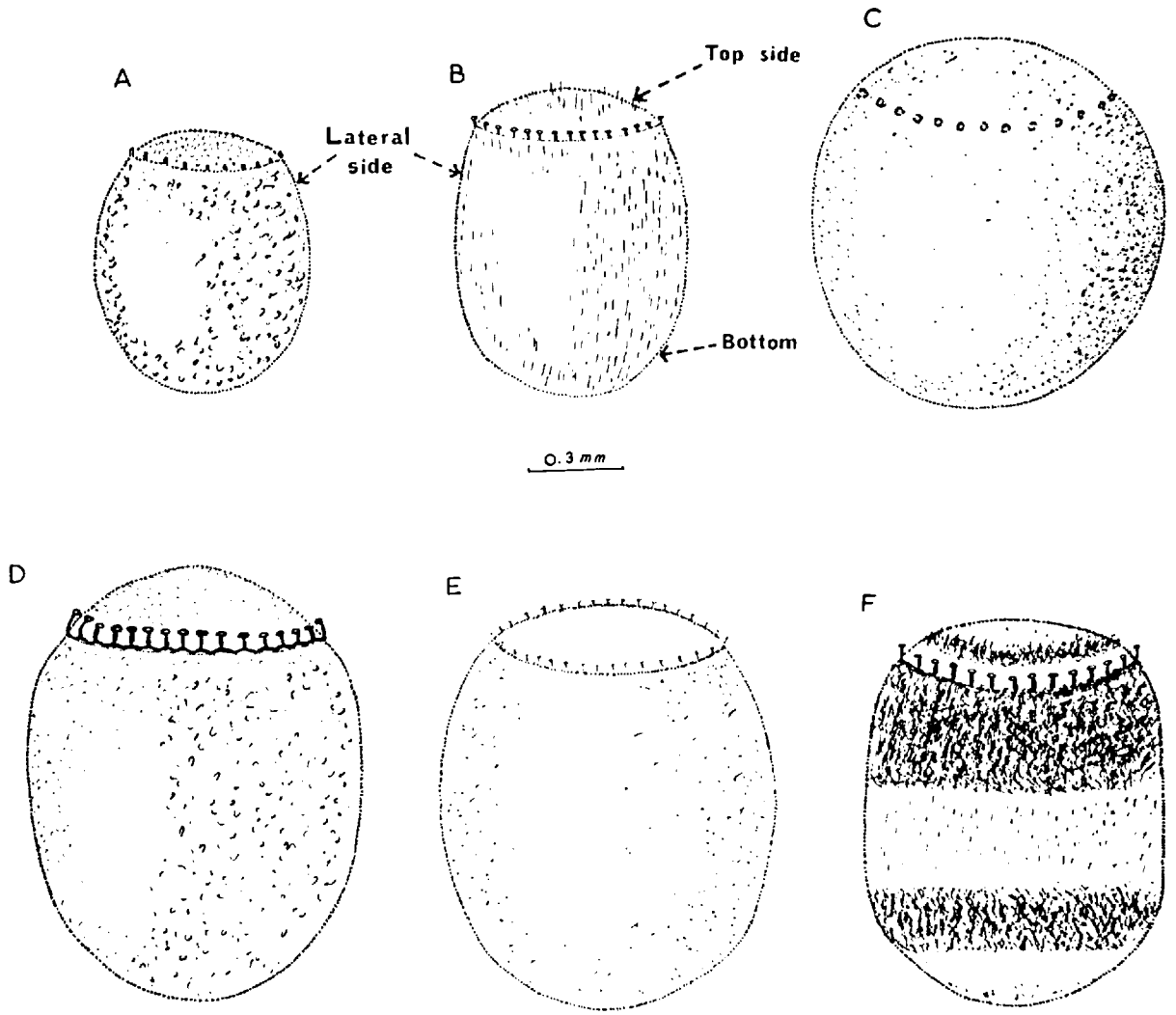


Fig. 40. Egg types of Pentatomoidea

A, Neottiglossa pusilla; B, Aelia acuminata; C, Eurygaster integriceps; D, Picromerus bidens; E, Palomena prasina; F, Piezodorus lituratus.

Asolcus waloffae sp.n.

Female: Body black. Antennae black throughout except the base of the scape and the extreme end of the pedicel which are reddish-yellow; radicle black. Mandibles tridentate, black, becoming reddish towards apex; wings hyaline, venation brownish. Legs brownish-yellow to reddish-yellow, except the coxae which are black; two apical segments of tarsi brownish, or dark.

Head: clearly transverse; weakly concave seen from above (fig. 44); its width distinctly greater than the greatest width of thorax (fig. 39). Frons and face rugose and hairy all over except the frontal line and the bulge of the antennal insertions which are rather shiny, smooth with very fine hairs. The distance between the lateral ocelli is twice that between the median ocellus and a lateral one. Eyes with a few minute scattered hairs; length of eye 1.5 greater than its greatest width. The end of the scape does not reach the median ocellus. Radicle black, smooth, three times longer than its width, whereas in A. ghorfii Del. and Voeg. and A. rufiventris Mayr (1908) (= A. anitis Nixon, 1939) it is shorter and brownish-yellow; scape black and hairy except at its base; it is longer and brownish-yellow in

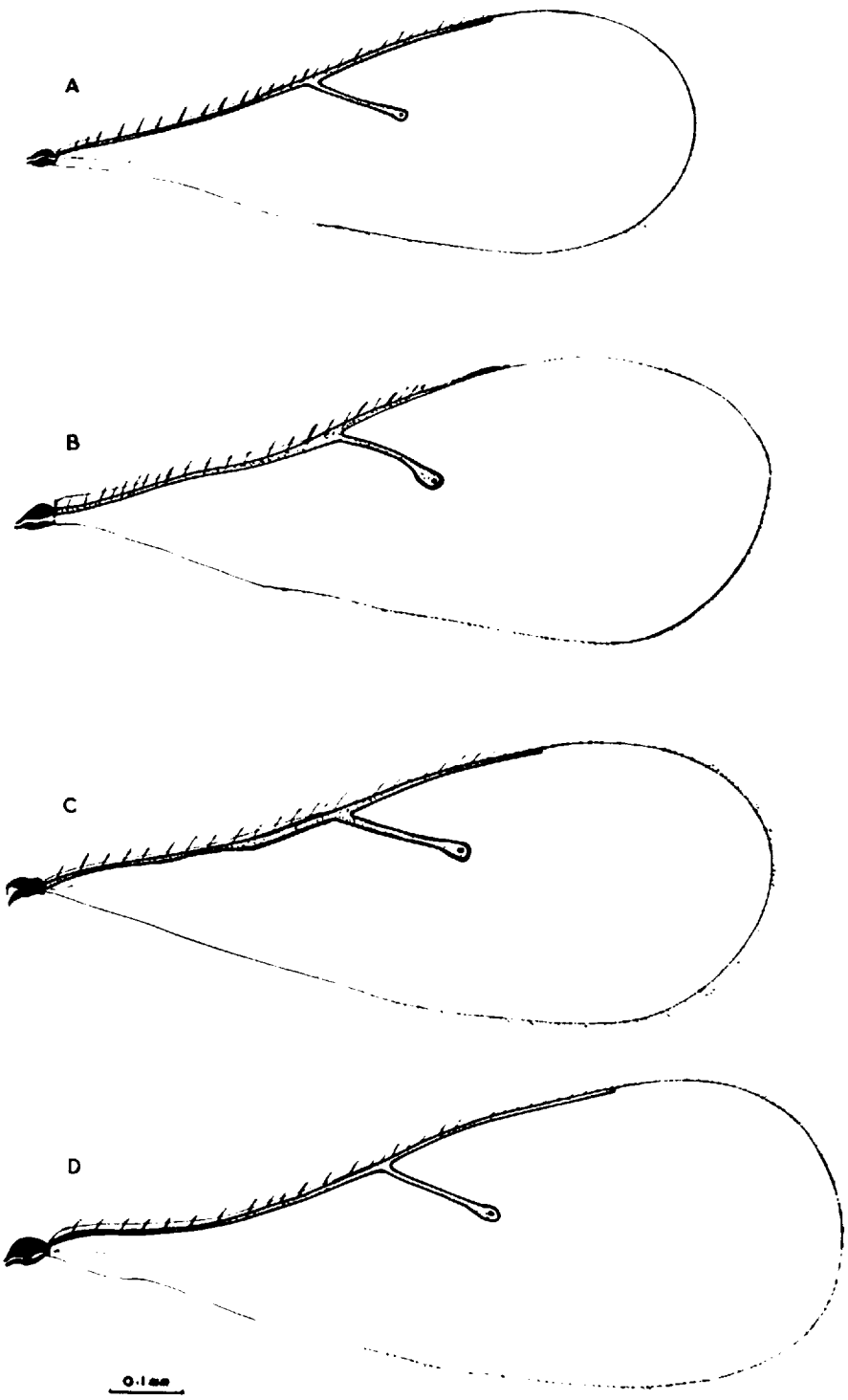


Fig. 41. Venational details of right fore wing of females are shown

A. Asolcus waloffae sp.n.; B. A. nigribasalis; C. A. bennisi; D. A. rungsi Voegelé

basalis Wollaston, bennisi Voegelé, nigribasalis Voegelé, rungsi Voegelé (1965) and rufiventris Mayr; pedicel slightly longer than the first segment of the flagellum, the latter being distinctly longer than the segment that follows; pedicel shorter than in nigribasalis; third segment of flagellum about the smallest, half the size of the pedicel; last six segments of the flagellum forming a club which is normal in shape and not particularly thick.

Thorax: pronotum and mesoscutum feebly shiny, and mostly with fine sculpture and hairs. Parapsidal furrows obscure, whereas they are conspicuous in ghorfii. The sculpture of the mesoscutum tends to form longitudinal elements. Scutellum dull, scaly-reticulate laterally, becoming weak and rather shiny medially; its greatest width is more than half that of the mesoscutum. Postscutellum swollen in the middle with a broken marginal line. Length of fore wing about twice the greatest width of the thorax, postmarginalis about twice as long as the stigmalis; the latter longer than the marginalis and differs from the above species (fig. 41).

Abdomen: a little wider than the greatest width of the thorax (50 : 47), but narrower than the head. The width of 2nd tergite is distinctly more than its greatest

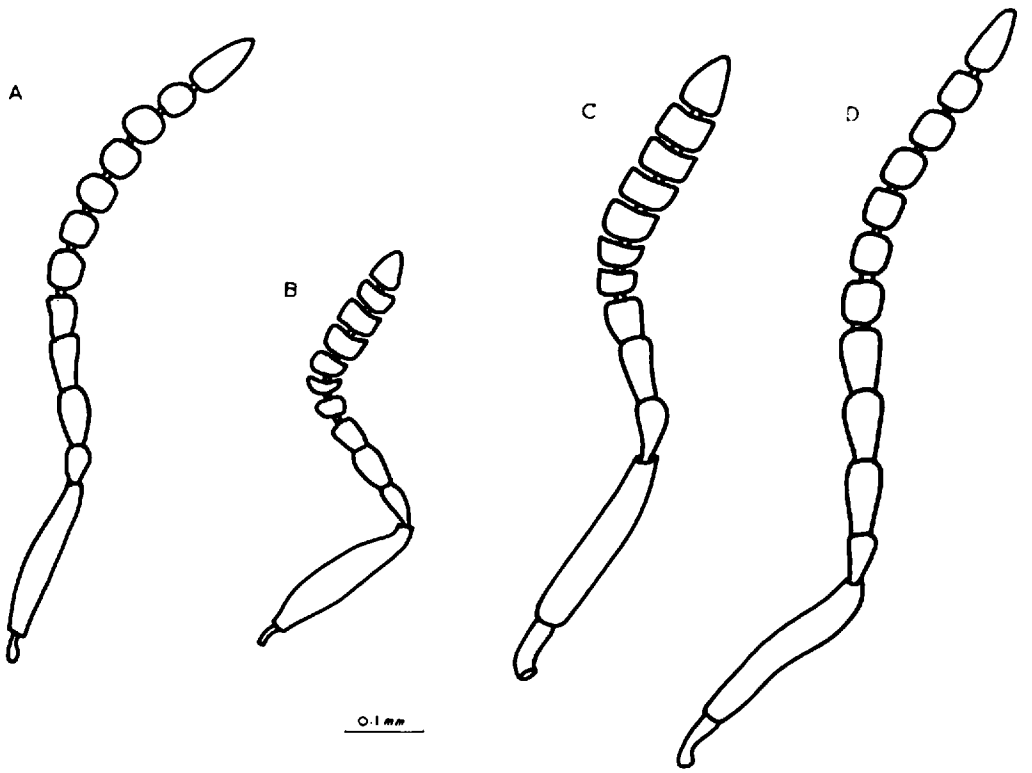


Fig. 42. Antenna of: A, B. Asolcus waloffae sp.n., ♂, ♀.
C, D. Asolcus davatchii sp.n., ♀, ♂.

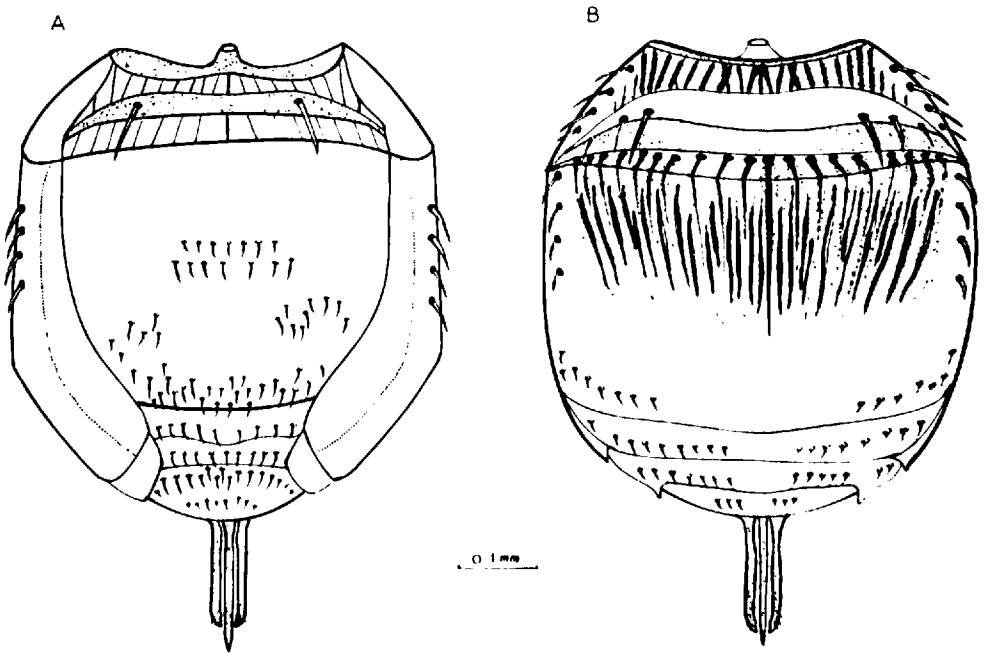


Fig. 43. Abdomen of Asolcus davatchii sp.n. with external ovipositor
A, ventral; B, dorsal.

median length (50 : 30). The length of 2nd tergite measured by the median line is more than three times greater than that of the first tergite (33 : 10). Furrows of first tergite very distinct; four lateral and one sublateral setae present; furrows of the 2nd tergite distinct over more than half its length; beyond this striate area there are about seven setae on each side, situated on a crescentic line. Remaining tergites dully, hairy, feebly punctate.

Length: 0.85 - 1.96 mm

Male: Like the female except in following details:-

Body narrower but of the same colour as in the female. Sculpture of head and thorax finer than in the female; in the region of the frontal line, the head is somewhat smooth, bare and shiny. Antennae (fig. 42) hairy and brownish-yellow in colour except the last four segments of the flagellum which are brownish; scape five times longer than radicle; pedicel small, somewhat conical and about half the length of the first segment of the flagellum; first segment of flagellum longer and stouter than the 2nd; segments 4 to 9 of flagellum subequal, more or less moniliform, except 8 and 9 which are slightly longer than wide; apical segment 1.5 times longer than the preceding segment.

Genitalia (fig. 46).

Length: 0.78 - 0.96 mm

Holotype female: England, Berks, Silwood Park, June 1965, bred from eggs of Aelia acuminata (L.).

Paratypes, male and female: Same data as above and also from Hants, Yateley.

Further material: Berks, Silwood Park; Hants, Yateley, June and July 1965, females swept from grass (probably overwintered

Host: A. acuminata and Neottiglossa pusilla (G.) in the field at Silwood and Yateley.

Bred in laboratory from eggs of Eurygaster integriceps Put.

This species did not parasitise batches of eggs of Piezodorus lituratus (F.) and Picromerus bidens (L.) placed in the field at Silwood and Cricket Hill, Yateley.

I dedicate this species to Dr. N. Waloff, whose interest and advice in this study encouraged me to discover this and the other species that form a complex of telenomid egg parasites of Pentatomoidea in Britain.

Asolcus davatchii sp.n.

Female: Body black. Antennae hairy throughout except the radicle and with a black club. Scape, pedicel and four following segments brownish-yellow (In some specimens occasionally brownish). Legs hairy, brownish-yellow except the coxae which are black. The wings are hyaline and their venation bright brownish.

Head: Very transverse; its width measured from above by a horizontal line passing through the lateral ocelli is about three times the greatest length measured by a vertical line passing through the median ocellus. Lateral ocelli almost touching the eyes; distance between them twice that between one of them and median ocellus. Head somewhat concave and dull, hairy and sculptured all over except around the median ocellus and the bulge of antennae; the latter conspicuous (fig. 44). The greater part of the frontal areas is clearly striated (fig. 44); these striations become weak in the areas of the frons and vertex, the pattern being a little different from the other closely related species. The sculpture of the frons towards the occipital carina is very fine. The length of the eye twice its width; the eyes bear some very fine minute hairs. The marginal orbits of the

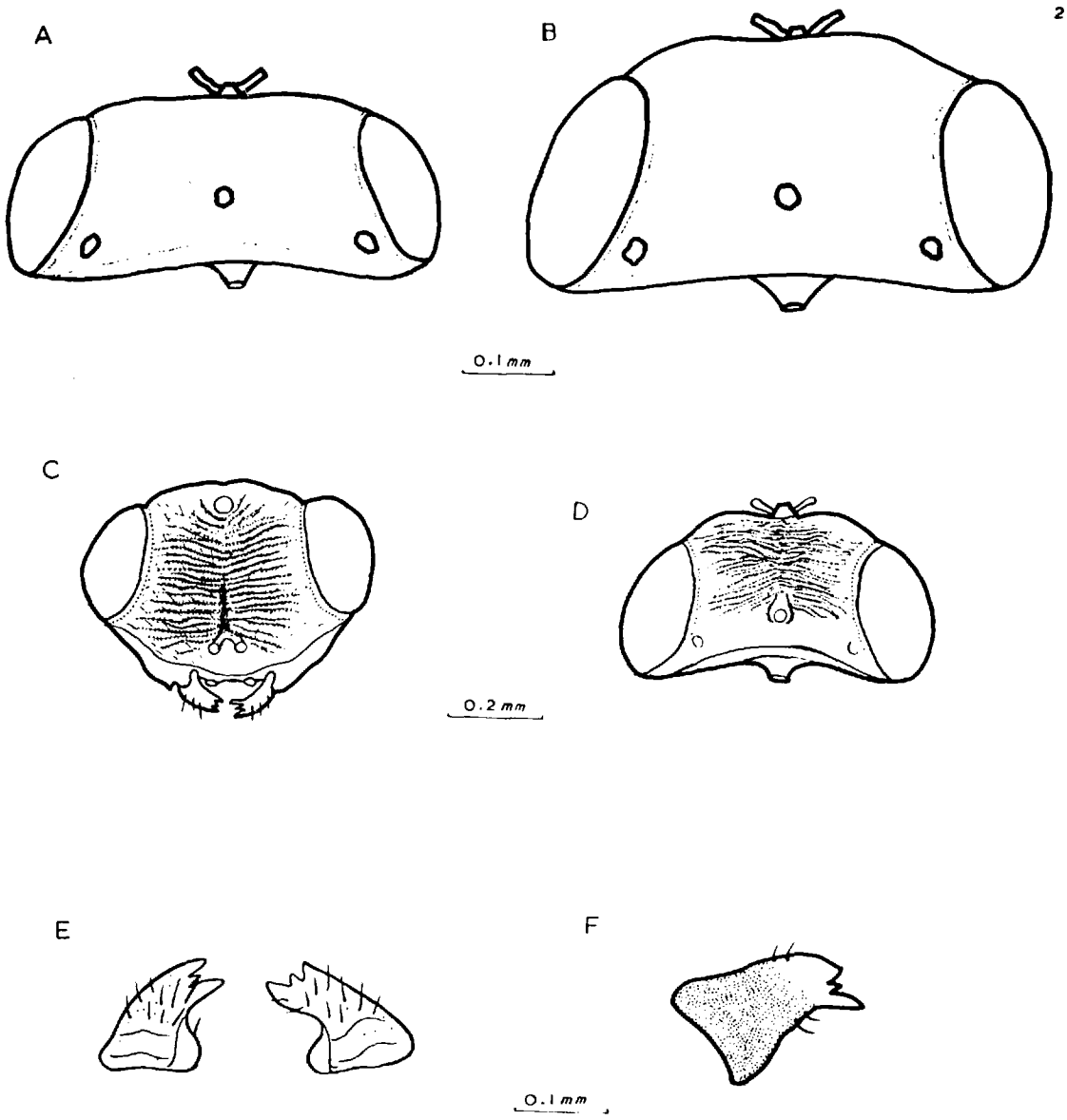


Fig. 44. Head and mandibles are shown. A, B, head from above of Asolcus waloffae sp. n., ♂, ♀; F, left mandible, ♀. C, head from in front. D, head from above of A. davatchii sp. n., ♀; E, mandibles, ♀.

eyes and the lateral ocelli are clear and somewhat shiny. Mandible thick, black with several rather long hairs, becoming feebly reddish towards the apex (fig. 44). Clypeus reticulate, becoming smooth and shiny along the apical margin.

Antennae: (fig. 42), pedicel at least three times longer than wide; distinctly shorter than the first segment of the flagellum but longer than the second; scape about five times longer than its greatest width; first segment of flagellum twice as long as the second and about twice its own greatest width; third segment of flagellum transverse and much shorter than the preceding segment. Last six segments forming a rather stout club of which the first segment is very transverse and brownish in some individuals.

Thorax: transverse, much wider than its greatest length (50 : 30). Pronotum dull and feebly punctate. Mesoscutum somewhat shiny, hairy, scaly-reticulate, but becoming distinctly striated posteriorly. Parapsidal furrows obscured by adjacent rugosity. Scutellum three times wider than its greatest length; feebly punctate and hairy all over, becoming shiny in the middle. Mesopleura finely punctate and hairy with a smooth and rather shiny broken marginal line. Coxae finely punctate. Length of fore wing a little more

than twice the greatest width of the thorax. Stigmalis rather short and about half as long as postmarginalis (fig. 45).

Abdomen: twice as long as the mesoscutum; its greatest width about that of the thorax, but shorter than the head. Second tergite three times longer than the first with lateral and sublateral setae present. Striations of the first tergite becoming smooth towards the apex and shiny in the middle. Nearly two thirds of the basal second tergite striated, smooth at apex; about fifteen setae form a crescentic line on each side at apex of the striated area. Remaining tergites feebly punctate and hairy (fig. 43).

Length: 1.05 - 1.36 mm

Male: Colour of body as in female. Size slightly smaller. Sculpture of head like that of female; its greatest width more than that of the thorax (57 : 50); the thorax a little wider than the abdomen (50 : 46).

Antennae: (fig. 42) radicle black and smooth; scape hairy, brownish-yellow; six times as long as its greatest width; pedicel rather short; about half as long as first segment of flagellum and equal to fourth flagellar segment, brownish-yellow and hairy; first segment of flagellum distinctly longer than the second; first four

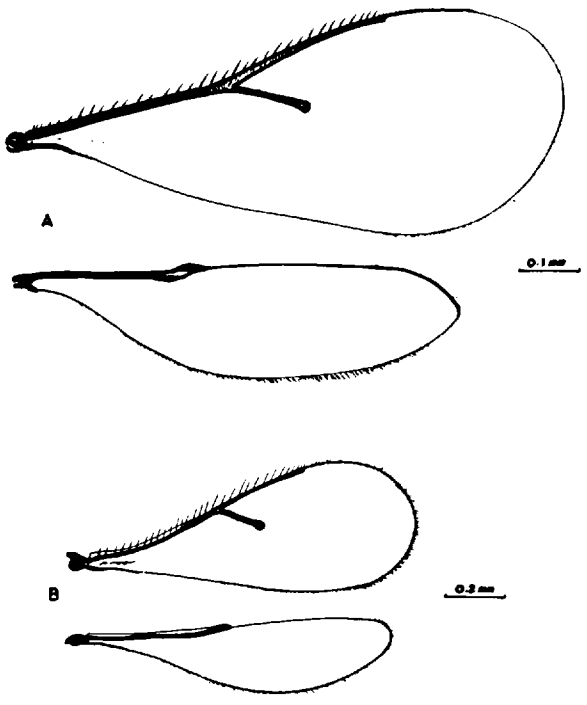


Fig. 45. Left wings are shown.

A. Asolcus waloffae sp.n. B. A. davatchii sp.n.

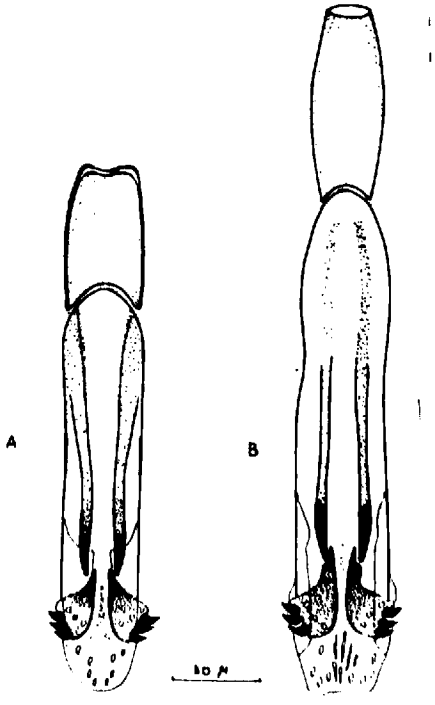


Fig. 46. Genitalia of: A. Asolcus waloffae sp.n. B. A. davatchii sp.n.

segments of flagellum same colour as pedicel and scape; second segment of flagellum slightly longer than the third but considerably longer than the fourth segment; fourth equal to fifth; segments 8 - 11 subequal; blackish in colour and hairy; apical segment conical, as long as the second. Legs same colour as in the female. Wings bright brownish-yellow. Length of fore wing more than twice the greatest width of the thorax, stigmalis about half as long as postmarginalis. The width of the second abdominal tergite is much greater than its length (48 : 32).

Genitalia (fig. 46).

Length: 1.0 - 1.25 mm

Holotype female: England, Berks, Silwood Park, June 1964, bred from egg of Palomena prasina (L.).

Paratype: Male and female: Same data as above but bred from eggs of Picromerus bidens (L.).

Further material: Berks, Silwood Park, Hants, Yateley, June and early July 1965, females beaten from broom, and two swept from grass (probably overwintered).

Host: Palomena prasina (L.) in the field (at Silwood and Yateley).

Bred in laboratory from eggs of P. bidens and in smaller numbers from Eurygaster integriceps. This Asolcus

did not parasitise batches of eggs of P. lituratus, A. acuminata, P. bidens and E. integriceps placed in the field at Silwood and at Cricket Hill, Yateley.

I take pleasure in dedicating this species to Professor A. Davatchi, Director of Applied Entomology, University of Tehran, for his interest, continuous advice, and for providing material for this study.

Asolcus silwoodensis sp.n.

Female: Body black. Antennae black and hairy throughout. Legs black and hairy apart from the first pair of tibiae and the first two segments of tarsi which are brownish at apex. Wings hyaline; venation rather thick and dark with blackish setae.

Head: strongly transverse and slightly convex (fig. 49). Head seen from in front with transverse striations starting from the frontal line and hairy almost all over (fig. 49). The striations of the frontal areas are clearly visible and shiny on top, except around the median orbit which is finely sculptured, seen from above its width measured along a horizontal line passing through the lateral ocelli three times its length measured along a vertical line passing through the median ocellus. Lateral ocelli very close to the margin of the eyes. Scape almost reaching the median ocellus; frons rugose, hairy. The bulge between the antennal insertion slightly visible. Distance between the lateral ocelli twice that between one of them and median ocellus. Mandibles tridentate very thick; black at base becoming reddish towards the apex.

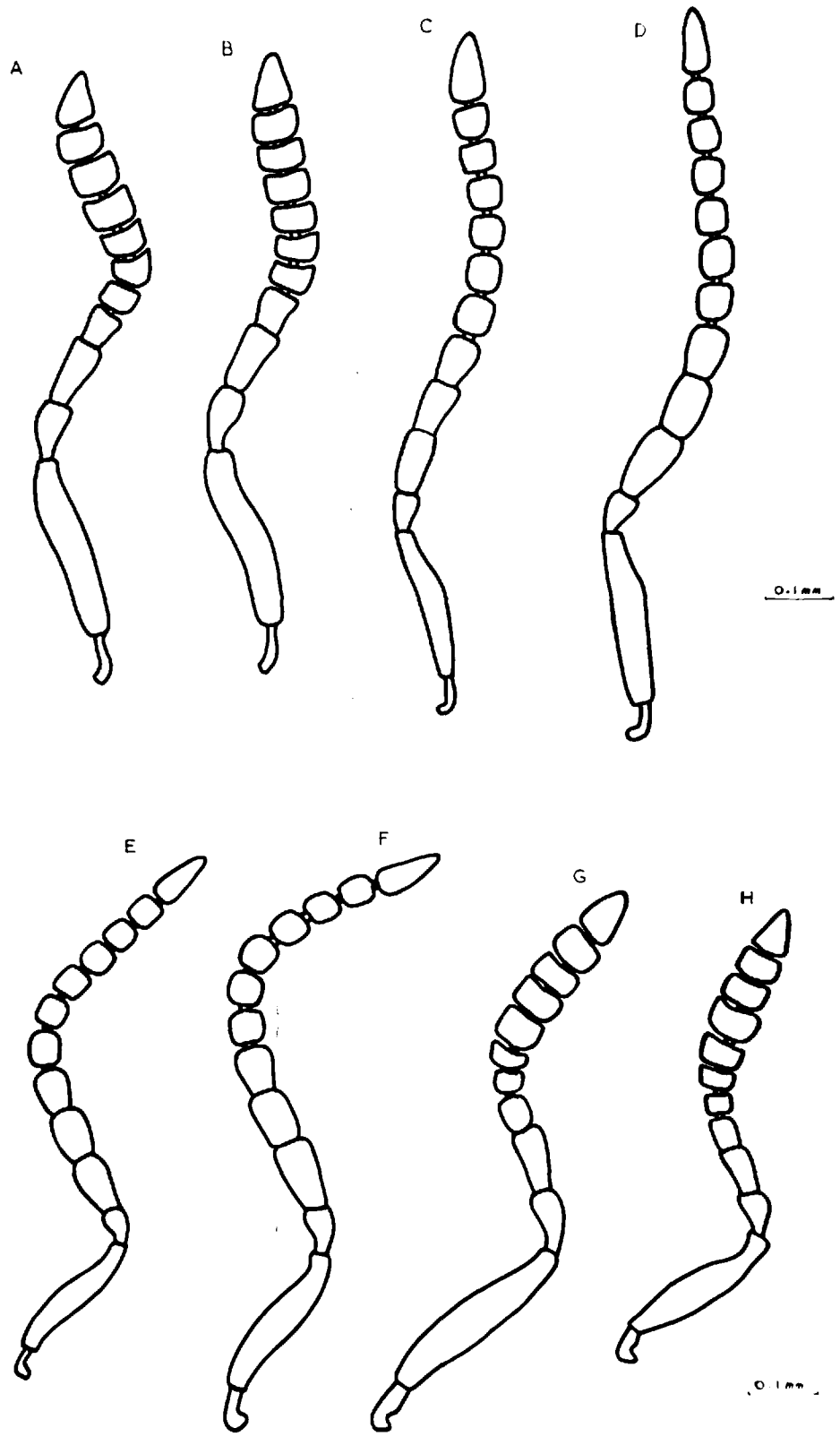


Fig. 47. Antenna of: A, C. Asolcus semistriatus NS (Delucchi) ♀, ♂.
B, D, A. nixo-martini sp.n., ♀, ♂. E, H, A. grandis TN (Delucchi) ♂, ♀.
F, G, A. silwoodensis sp.n., ♂, ♀.

Antennae: (fig. 47) Radicle smooth, three times longer than its width. Scape rather long; its length about six times its greatest width and slightly longer than in grandis, nixo-martini and semistriatus (fig. 47). Pedicel conical and long, but distinctly shorter than the first segment of the flagellum; first segment of flagellar rather narrow, twice as long as the second. This first flagellar segment is clearly longer than in grandis; third segment the smallest; last six segments forming a club which is of normal shape for the genus and not particularly stout.

Thorax: About as wide as the second tergite but narrower than the head (60 : 55). Pronotum finely sculptured and hairy. Mesoscutum distinctly longer than wide (50 : 30), rugose and hairy; the rugosity striate posteriorly; parapsidal furrows absent. Scutellum finely sculptured and feebly hairy; its greatest width more than three times its length. Postscutellum slightly swollen and punctate. Mesopleurae hairy and somewhat smooth. Wings cloudy, venation blackish; length of fore wing nearly two and a half times the greatest width of thorax; it is longer than in the three closely related species (fig. 48); stigmalis long, twice the length of

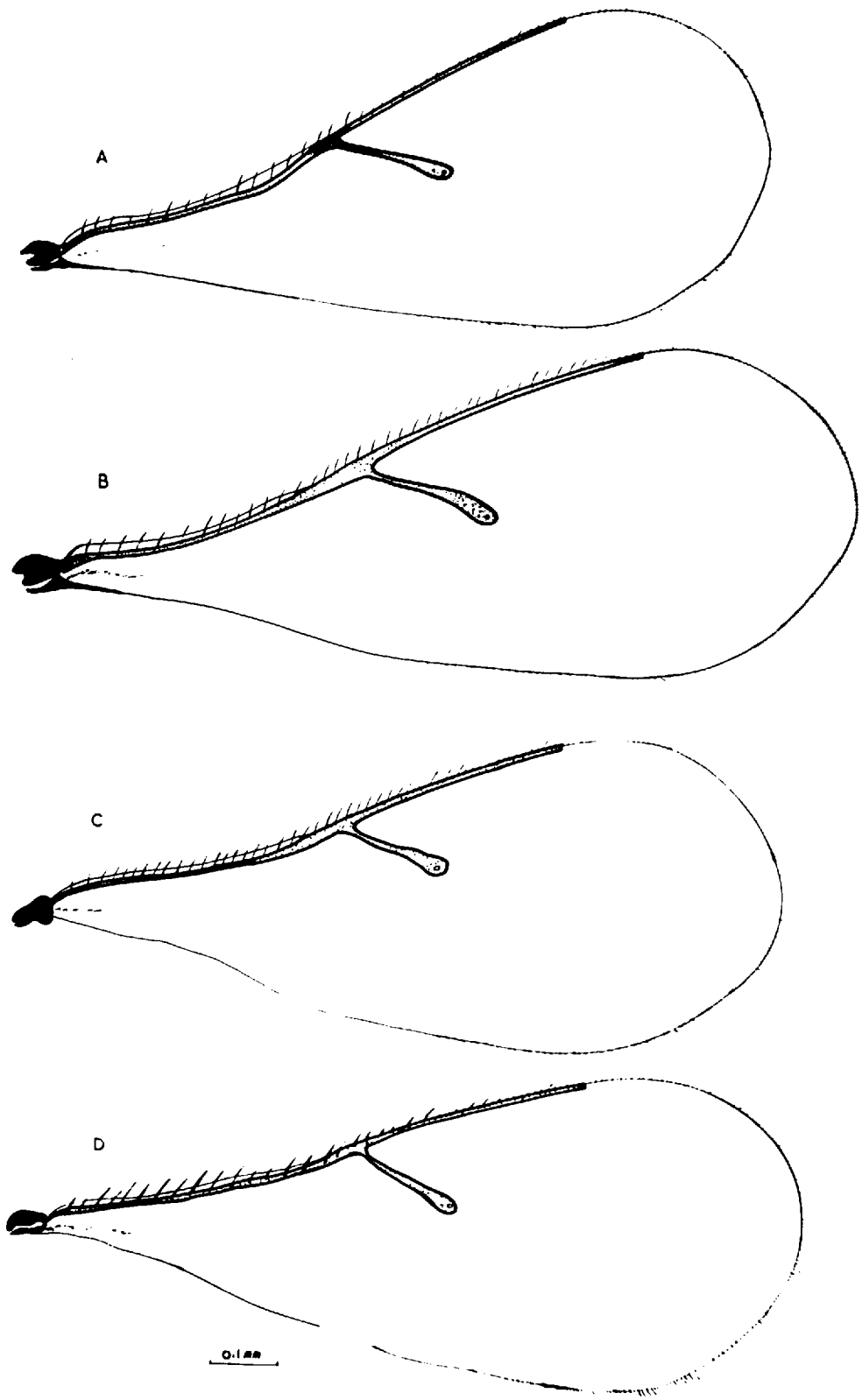


Fig. 48. Right fore wing of females are shown. A, Asolcus grandis Th (Delucchi). B, A. silwoodensis sp.n. C, A. semistriatus N.S. (Delucchi). D, A. nixo-martini sp.n.

marginalis but less than half that of postmarginalis.

Abdomen: About as wide as long (56 : 56). First tergite striated; its greatest width five times its length (50 : 10); four lateral and one sublateral setae present. Second tergite wider than long (56 : 40); the greater part of its surface striated; these striations become weak towards the apex; about fifteen setae on each side form a crescentic line at apex of striated area. Remaining tergites finely punctate and hairy.

Length: 0.9 - 1.5 mm (see fig. 50).

Male: Black like the female; head slightly wider than the thorax (54 : 50); its sculpture like that of the female. Antennae always black and hairy throughout; radicle three times as long as wide; scape five times its greatest width and distinctly longer and stouter than in grandis (fig. 47); pedicel small, a little shorter than the fourth segment of flagellum; first segment of flagellum about one and a half times as long as the second, distinctly long and stouter than in grandis and semistriatus (fig. 47); second segment clearly longer than the third; third longer than the fourth; segments 8 - 11 subequal; apical segment conical; about as long as the first. Legs

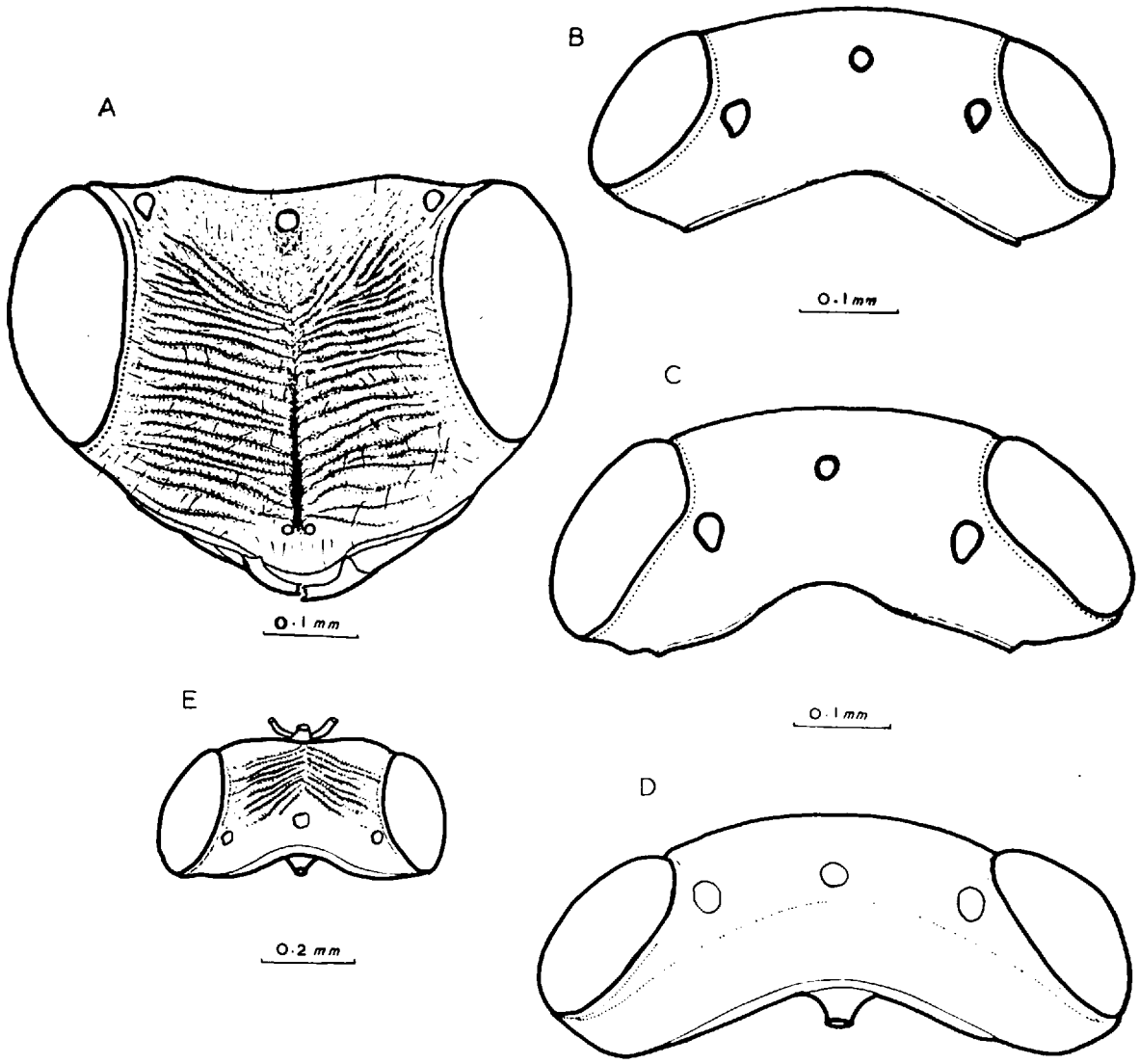


Fig. 49. **Head of females of:** A, Asolcus nixo-martini sp.n., **from front.**. B, C, D, E, **from above:** B, A. semistriatus NS (Delucchi); C, A. nixo-martini sp.n.; D, E, A. silwoodensis sp.n.

black throughout apart from the front tibiae and the tarsi which are slightly brownish; the front tibiae are always brownish-yellow in nixo-martini and semistriatus, and almost so in grandis. Wings clearer than in the female; length of the fore wing more than twice that of the thorax. Genitalia longer and diffeerent in degree of chitinisation from that of the other closely related species (fig. 51).

Length: 0.8 - 1.2 mm (see fig. 50).

Holotype female: England, Berks, Silwood Park, June 1964, bred from eggs of P. lituratus.

Paratypes males and females: Silwood Park; Hants, New Forest and Yateley, May and June 1965, 1966, from eggs of P. lituratus; Kent, August 1965, females captured on gorse.

Further material: Berks, Silwood Park, Hants, Yateley and New Forest, May and June 1965, 1966, females beaten from gorse and broom (probably overwintered).

Host: P. lituratus in field.

Bred in laboratory from eggs of A. acuminata, N. pusilla, E. integriceps, P. lituratus, P. bidens, P. prasina and Coreus marginatus (L.).

This species parasitised batches of eggs of E. integriceps and P. bidens placed in the field at Silwood and Yateley.

It gives me pleasure to name this species after Silwood Park in appreciation of the help and assistance I received there during my study at the Imperial College Field Station.

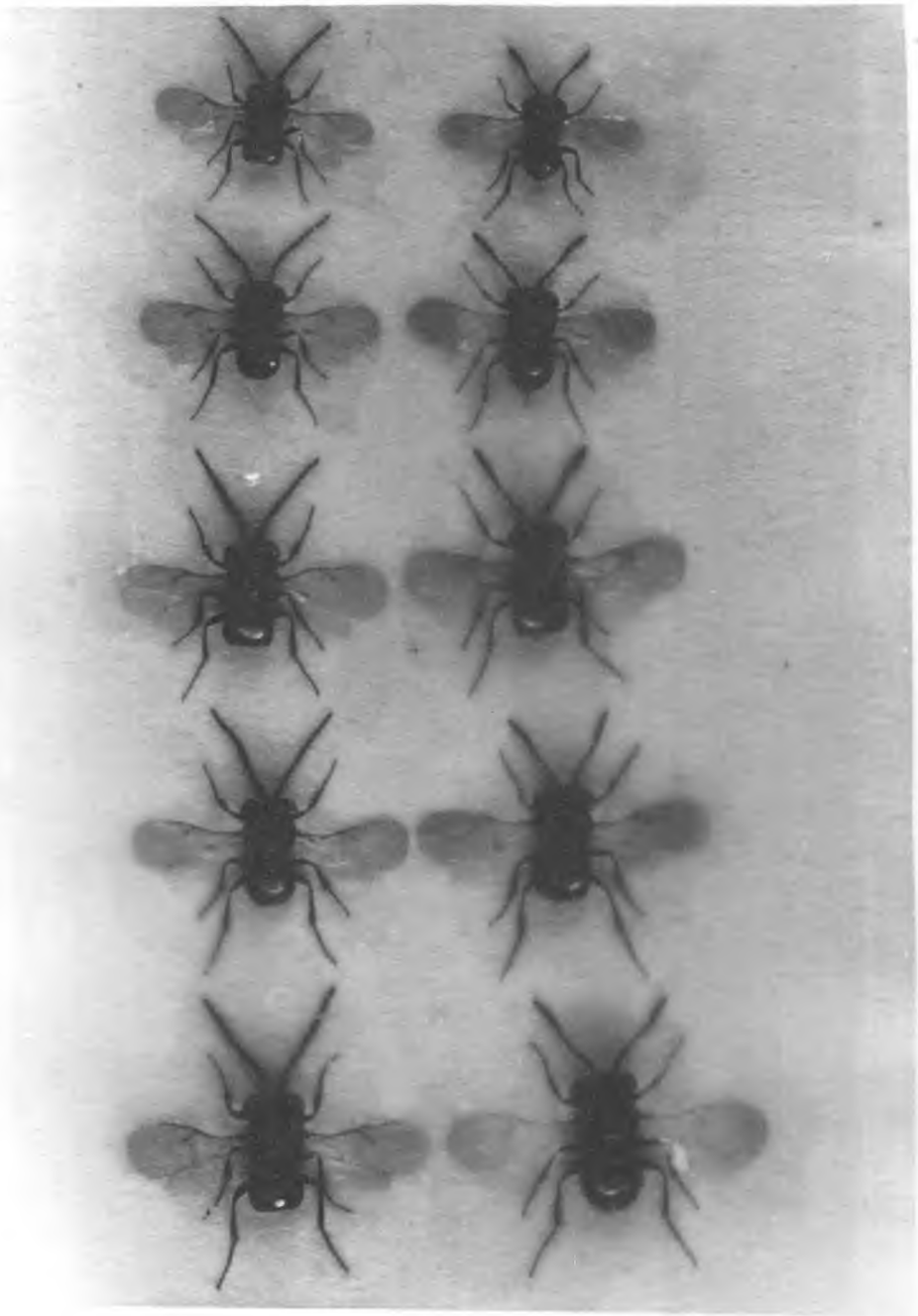


Fig.50

Variation in size of a pair (female on the right) of Asolcus silwoodensis sp.n. bred from the eggs of Pentatomoidea as shown below :

1)Neottiglossa pusilla (G.), 2) Aelia acuminata (L.),

3)Piezodorus lituratus (F.), 4) Eurygaster integriceps Put.

5)Palomena prasina (L.) or Picromerus bidens (L.)

(Scale : Female bred from the egg of Aelia is 1.0 mm in length)

Asolcus nixo-martini sp.n.

Closely related to grandis, semistriatus and silwoodensis with all of which it may be compared as follows:-

Female: Body almost as in silwoodensis apart from the head which is somewhat concave (fig. 49). Head striations towards the lateral ocelli are distinct, whereas they are weak in semistriatus and almost absent in grandis. Lateral ocelli not clearly visible as in the other species. Mandible slightly narrower than that of silwoodensis. Rugosity of head similar to that of silwoodensis but stronger than in grandis and semistriatus.

Antennae: As in semistriatus: radicle, scape, pedicel and first segment of flagellum longer than in grandis but shorter than in silwoodensis (fig. 47).

Thorax: Mesoscutum strongly rugose, as in silwoodensis but the rugosity finer in grandis and semistriatus. Fore wing similar to that of grandis but distinctly different from that of silwoodensis and semistriatus (fig. 48). Front tibiae brownish-yellow, as in A. semistriatus; in grandis only the middle tibia is brownish while in silwoodensis it is deep brown or blackish throughout; the middle tibiae

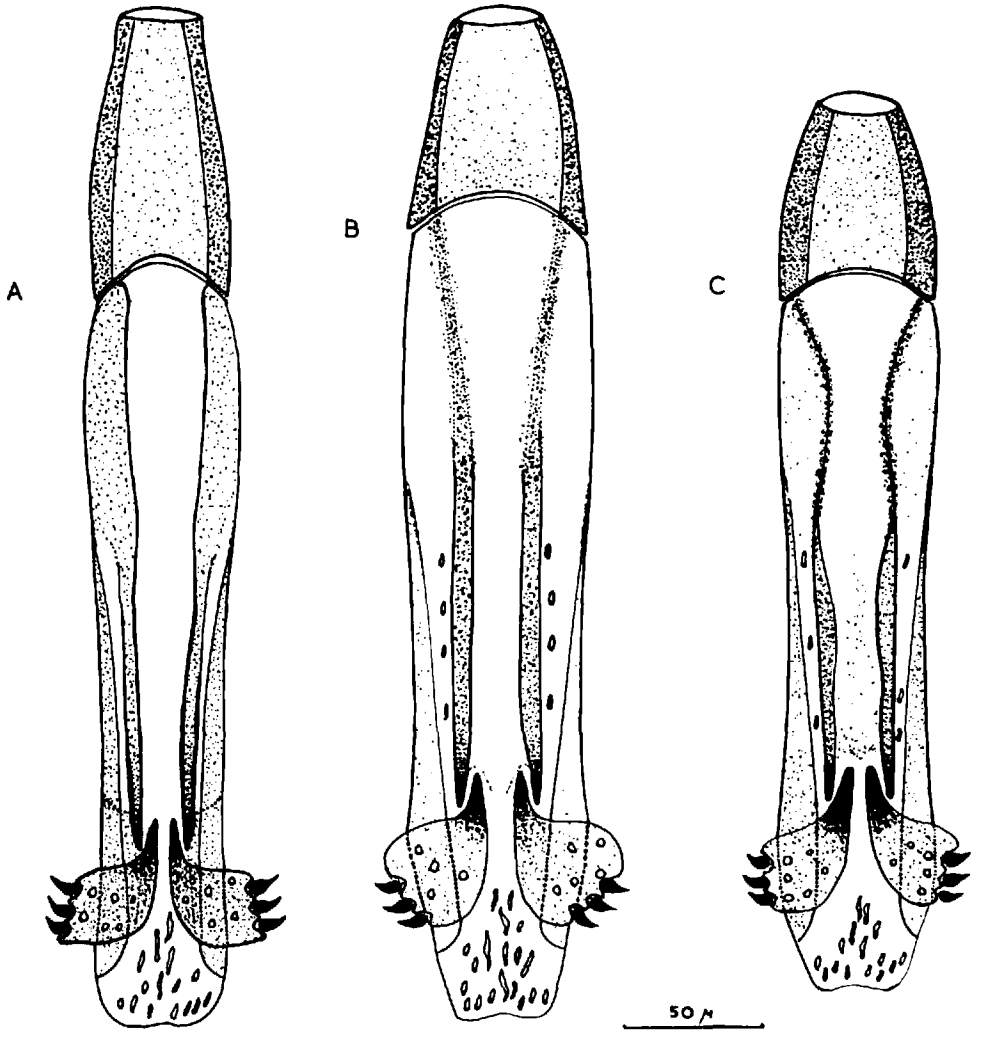


Fig. 51. Genitalia of: A, Asolcus silwoodensis sp.n.; B, A. niko-martini sp.n.; C, A. semistriatus NS (Delucchi). All males emerged from eggs of Picromerus bidens (L) at 28°C

almost black except at both extremities which are brownish-yellow as in grandis; the middle tibia is always brownish-yellow in semistriatus and black in A. silwoodensis.

Male: First segment of flagellum distinctly longer than in grandis and semistriatus; segments 6 - 11 are clearly longer than wide; in the three other species they are subequal (fig. 47).

Genitalia also different in form, length and degree of chitinisation from other related species (fig. 51); the genitalia of the four species were found to be always symmetrical (fig. 51); in Nixon's figure (1939, page 133) the claspers of semistriatus Ns (Nixon) show 3 teeth on one side and two on the other.

Length: 0.8 - 1.2 mm

Holotype female: England, Berks, Silwood Park, June 1963, bred from eggs of P. lituratus.

Paratypes males and females: Silwood Park, June 1964 and 1965, May and June 1966, Yateley June 1965 and 1966.

Further material: Berks, Silwood Park, June 1964, 1965 and May 1966, Yateley May and June 1965, 1966, females beaten from gorse and broom (probably overwintered).

Host: P. lituratus in the field.

Bred in laboratory from eggs of A. acuminata, N. pusilla E. integriceps, P. lituratus, P. bidens and P. prasina.

This species parasitised batches of eggs of E. integriceps and P. bidens placed in the open at Silwood Park and Yateley.

I dedicate this species to Mr. G. E. J. Nixon of the Commonwealth Institute of Entomology and to Dr. H. E. Martin F.A.O. expert in plant protection for their interest and helpful advice as well as for providing material for part of this work.

Relationships of A. nixo-martini and A. silwoodensis with other species

The specimens of nixo-martini and silwoodensis were identified as semistriatus and grandis by Mr. Nixon; the former species was also identified as semistriatus at F.A.O. Sunn Pest Information and Documentation Centre, Paris, by Dr. G. Remaudière. After a three year detailed study of the biology, ecology and comparative taxonomy of these Asolcus the above identification did not appear to be acceptable.

Attempts to cross-breed the four species were unsuccessful since only male progeny was produced. A comparison

of grandis, nixo-martini, semistriatus and silwoodensis based on specimens bred on the same host, namely, on Picromerus bidens (L.), under the same conditions revealed, in my opinion, satisfactory morphological characters for separating them. This comparative study suggests that nixo-martini is more closely related to grandis and semistriatus than is silwoodensis. The females of these four closely related species never mated except with the males of their own species. The females of grandis rarely parasitised or hatched from the eggs of P. bidens, whereas the eggs of this host were found to be very suitable for breeding the other three species. Moreover, a preliminary survey on the distribution of the telenomids attacking the eggs of Pentatomoidea in Britain also indicated that silwoodensis was the most common Asolcus and had a much wider distribution in southern England than nixo-martini.

Thus, in view of the above evidence, it seems reasonable to accept the existence of four species. It seems desirable that more experimental breeding should be carried out to determine the validity of the other closely related species, so that a more reliable classification of these difficult scelionid parasites may be achieved.

II Genus Telenomus Haliday (1833)

Body normally narrow (fig. 52). Frons smooth and glabrous in greater part. Eyes hairy and large (fig.53,56). Antennae of female usually with 11 segments (club of 5 segments (fig.53,56). Antennae of male with 12 segments, the segments 3 - 5 elongate, and 6 - 11 ovate and all similar in size and shape. Pedicel and last segment conical in both sexes. Mandibles narrow and tridentate. Head wider than thorax. Mesoscutum finely sculptured; parapsidal furrows absent. Scutellum smooth or feebly sculptured laterally. Hind wing usually narrow with a long fringe (fig. 54). Stigmalis rather long. Abdomen elongated, distinctly longer than its greatest width. Second abdominal tergite rather long, striated at base; these striations very short and never reaching beyond the middle of the sclerite.

The two species dealt with in this work may be separated thus:-

1 Legs clay-yellow in male and deep brownish in female. Behind the lateral ocelli with a sharp transverse ledge (fig. 53). Size larger. Hind wing rather broad; that of male very large. Antennae black in female but

slightly brownish in male. Stigmalis rather long.....
..... T. truncatus (Mayr)

– Legs brownish-yellow in both sexes. Size smaller. No transverse ledge behind the lateral ocelli in both sexes. Hind wing narrow; that of male of normal size. Radicle and scape brownish-yellow in male. Antennae black in female. Stigmalis rather short... T. sokolovi (Mayr)

A)

B)

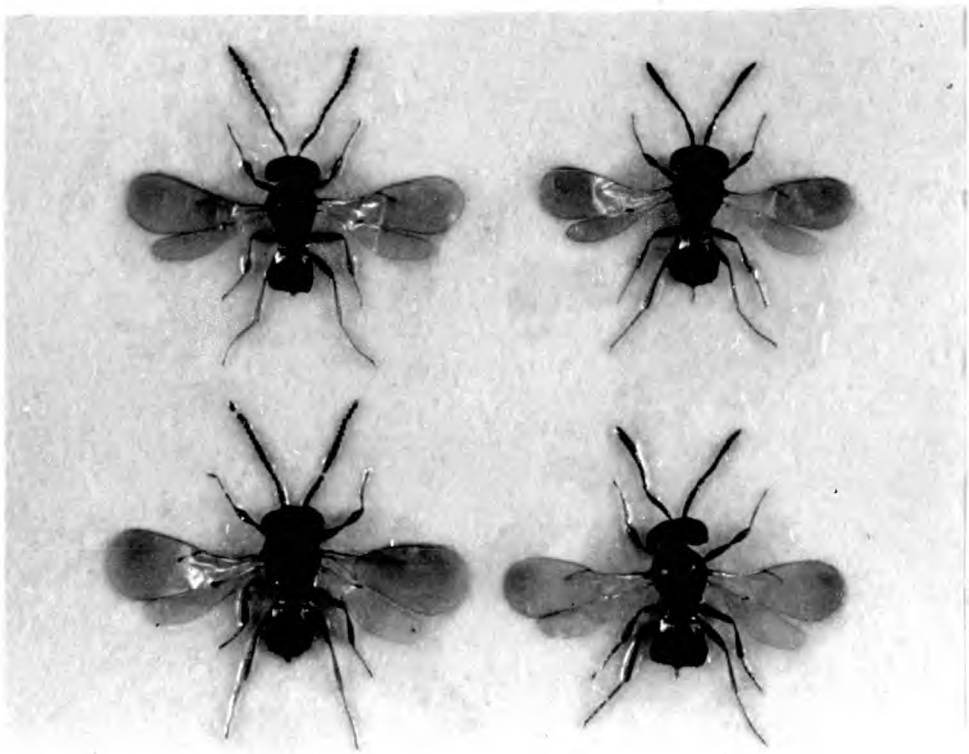


Fig. 52 – A, a pair of Telenomus sokolovi (female on the right); B, a pair of Telenomus truncatus (female on the right).

Telenomus truncatus Mayr (1879)

This species seems to be intermediate between *Telenomus* and *Asolcus*. It was apparently first described by Nees (1834) as *Telenomus truncatus* and redescribed by Mayr (1879) and Kieffer (1926). Although the general form of the body, characters of the head, antennae, thorax and abdomen place this species in the genus *Telenomus*, the presence of very minute and scattered hairs on the eyes with rather broad hind wings indicated that it is not typical of this genus.

The specimens sent to the British Museum (Natural History) were identified as *Asolcus truncatus* (Mayr) by Mr.Nixon in 1965 but later he identified this species as *Telenomus truncatus* (Mayr) in 1966. Since Kieffer's description (1926) needs amplification I redescribe the species as follows:-

Female: Body black. Antennae black throughout except at the extreme apex of scape and pedicel which are brownish in some individuals. Legs hairy, coxae black; trochanters dark brown; femora black except at apex which is brownish. The tibiae and tarsi are dark brown. (Both tibiae and tarsi sometimes also brownish in individuals bred in the laboratory). Wings and venation dark brown.

Head: transverse and weakly concave (Fig. 53). Its width, measured by a horizontal line passing through the later ocelli is two and a half times its length (50 : 20), measured by a vertical line passing through the median ocellus. The width of the head is more than that of the thorax (50 : 42). Frons seen from above shagreened-punctate around and between the ocelli. The later ocelli almost touching the eyes. Vertex shagreened - reticulate. Behind each lateral ocellus, there is a sharp transverse ledge which joins the end of a wide groove which reaches the hind margin of the eye. The genal sulcus is finely punctate. Face, as far as median ocellus, and particularly the frontal areas, smooth and shiny. Eyes rather large with some very minute hairs. No distinct bulge between the lateral insertion of the radicle and base of eye. Radicle bare, three times as long as wide; scape rather slender; its length five times its greatest width; pedicel shorter than the first segment of the flagellum; first segment of flagellum twice as long as second; third segment shorter than the second, but distinctly longer than the third, the last 5 segments form a narrow club (fig. 53). Mandible tridentate, narrow and brownish towards the apex.

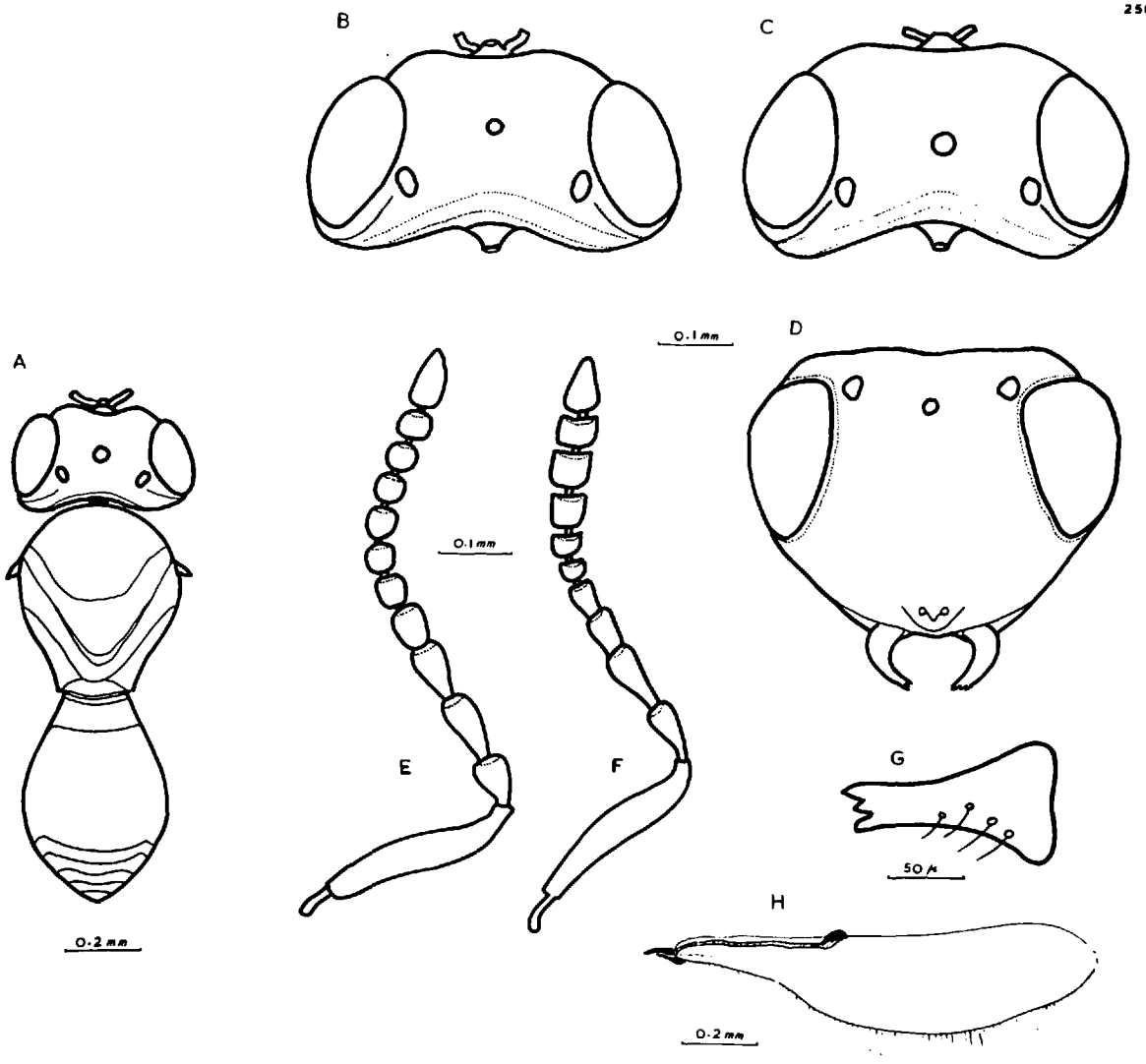


Fig. 53. Telenomus truncatus Mayr: A, outline of male body. B,C, head from above of ♂, ♀. D, head from in front, ♀. E,F, antennae of ♂, ♀. G, right mandible, ♀. H, right hind wing, ♀.

Thorax: slightly longer than wide (46 : 42), narrower than the head. Pronotum finely sculptured. Mesoscutum rugose-punctate, hairy and matt, but becoming somewhat shiny in the middle; the sculpture forms weak longitudinal elements. Parapsidal furrows absent. Scutellum smooth and shiny; its width nearly twice its length. Postscutellum rugose and dull with a broken marginal line. Length of fore wing three times the greatest width of thorax; stigmalis rather long; at least half as long as postmarginalis; hind wing broad (fig. 53), its fringe less than half its greatest width.

Abdomen: Somewhat elongate, longer than its width (50 : 40). First tergite three times as wide as its greatest length; four lateral and one sublateral setae present; second tergite nearly as wide as long; weakly striated at base. The number of lateral hairs near the apex fewer than in the four British species of Asolcus dealt with in this paper. Remaining tergites somewhat smooth and with somewhat long, sparse hairs.

Length: 1.2 - 1.5 mm

Male: colouration of the body as in the female. Sculpture of the frons more distinct than in the female.

Antennae (fig. 53) brown to almost black, particularly the flagellum. Scape rather slender, its length at least five times its greatest width; pedicel conical and clearly shorter than the first segment of the flagellum; first segment of flagellum distinctly longer and narrower than the second, twice as long as wide; second segment longer than the third; segments 6 - 11 subequal; apical segment conical, about as long as the third segment. Mandible tridentate; narrow and brownish (fig. 53). Mesoscutum and scutellum as in the females; the latter laterally more hairy than in the female. Fore wing larger than in the female; its length more than three times the greatest width of the thorax. Coxae black; the rest of the legs clay-yellow except the femora and the last segment of the tarsi which are dark brownish. Abdomen more slender than in the female. The striations on the second tergite very weak and short.

Genitalia (fig. 56).

Length: 1.1 - 1.3 mm

Females: England, Hants, Yateley, New Forest, May 1965, 1966, beaten from gorse (probably overwintered).

Females and males: Hants, Yateley and New Forest,

Surrey, Wisley Common, June July, August 1965 and 1966. bred from eggs of P. lituratus collected on gorse.

Females: Berks, Silwood Park, June and July 1965, three specimens captured on broom by beating.

Host: P. lituratus in field.

Bred in laboratory from eggs of A. acuminata, E. integriceps, P. lituratus, P. prasina and P. bidens.

This species parasitised batches of eggs of E. integriceps and P. bidens placed in the open at Yateley, May, June and July 1965.

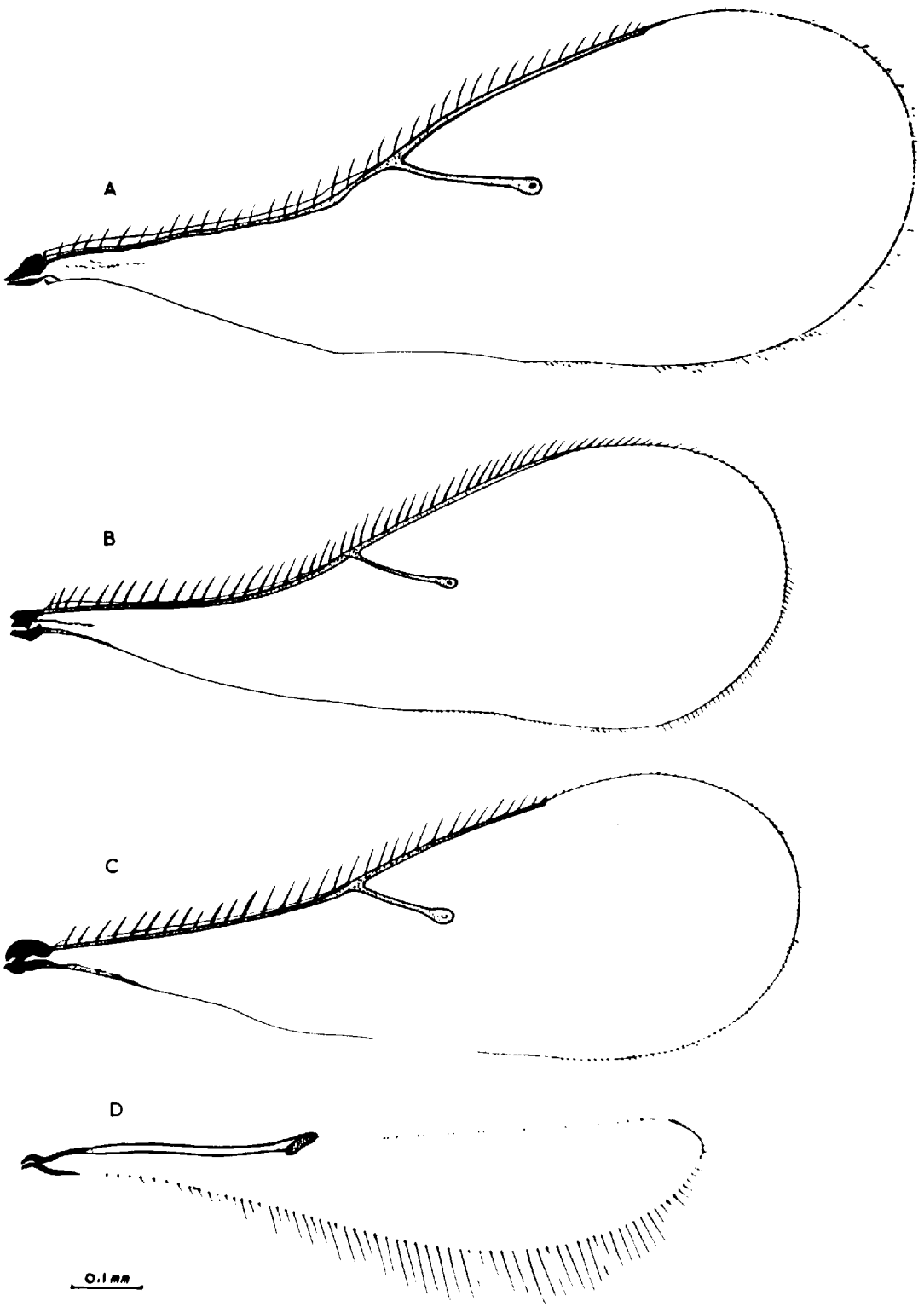


Fig. 54. A,B,C, Right fore wings of females of : A. Telenomus truncatus Mayr; B, (Russian) C, (British); D, hind wing of ♀ T. sokolovi Mayr

Telenomus sokolovi MAYR (1897)

This species is close to Telenomus tischleri Nixon (1939) (= T. truncatus Ns (Masner), 1958) and, indeed, specimens sent to the British Museum (Natural History) were identified as tischleri by Mr.Nixon in 1965.

A comparative study of the morphology of this species and of T. sokolovi (Russian specimens), both bred from Eurygaster integriceps suggest that they are the same species, but different from T. tischleri which was bred from Dolycoris baccarum L. in Germany in 1938.

Although slight differences were found in the fore wing of the British specimens and that of T. sokolovi from Russia (fig. 54), I think that the name sokolovi should be used for the material from Britain until further experimental work can be carried out on the species. The following is my comparison of sokolovi with truncatus:

Female: Body black, smaller than truncatus. No sharp transverse ledge behind the lateral ocelli. Antennae black and hairy except the radicle, the apex of scape and the extreme apex of pedicel which are brownish. Legs brownish-yellow except the femora and the apical segment·

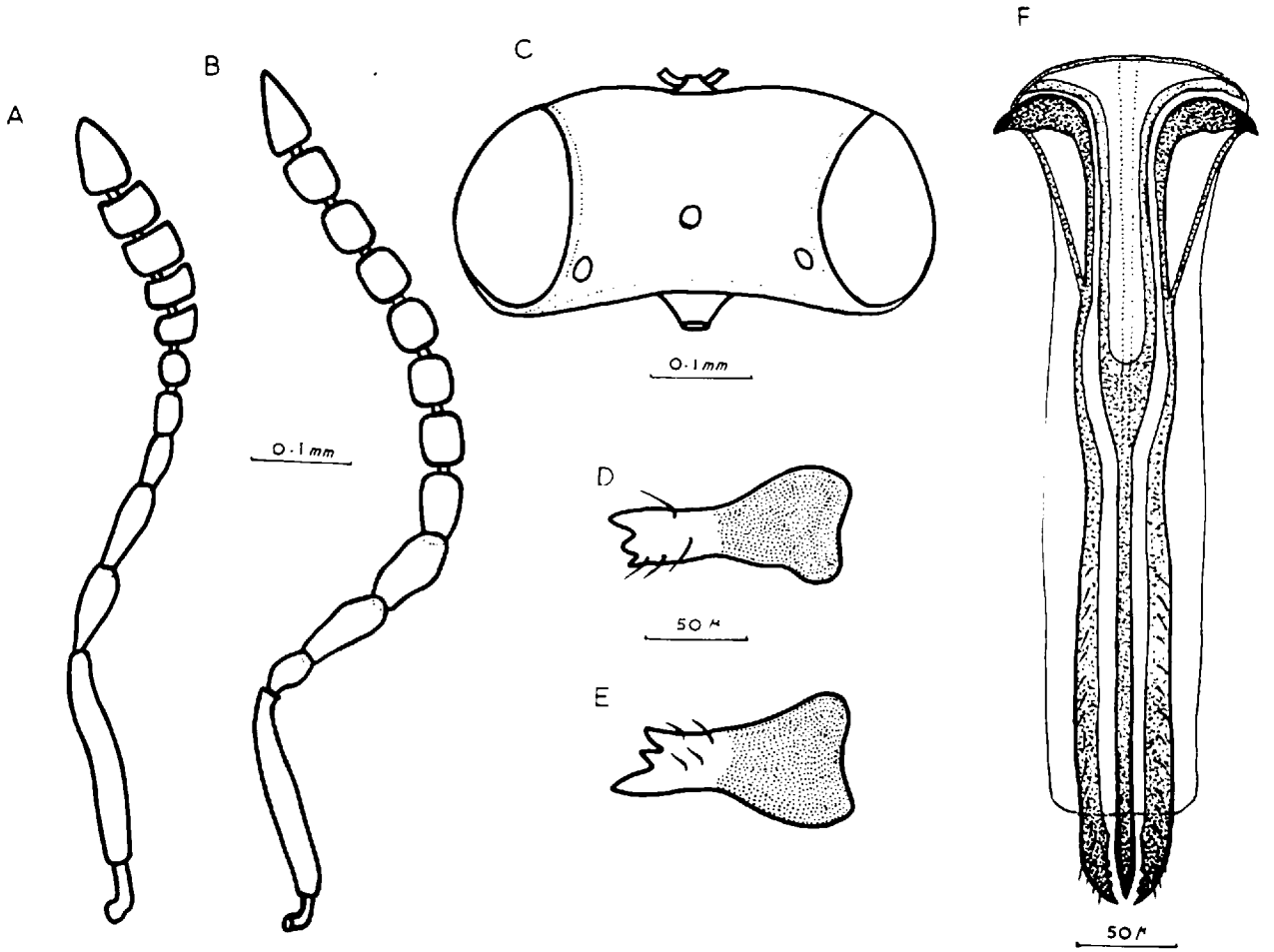


Fig. 55. Telenomus sokolovi **Mayr.** A, B, antenna of ♀ and ♂; C, head from above; D, E, right and left mandibles; F, ovipositor (ventral view)

of tarsi which are slightly brownish. Coxae black apart from extreme ends which are brownish.

Head: seen from the front with a row of punctures along the inner eye-margin. Eyes rather large and distinctly covered with hairs. Head clearly wider than the thorax (57 : 40).

Antennae (fig. 55): radicle bare, about three times as long as wide; scape very slender; its length five times its greatest width; pedicel clearly shorter than the first segment of flagellum; first segment of flagellum very slender; one and a half times as long as the second segment, second segment also slender and distinctly longer than the third, fourther segment the smallest; apical five segments forming a narrow club.

Thorax: similar to that of T. truncatus. Stigmalis slightly shorter and darker in British specimens than in the Russian specimens (fig. 54).

Abdomen: Similar to that of A. truncatus. Ovipositor (fig. 55). Length: 1.1 - 1.3 mm

Male: Differs from female as follows:-

Size smaller.

Antennae (fig. 55); radicle and scape usually

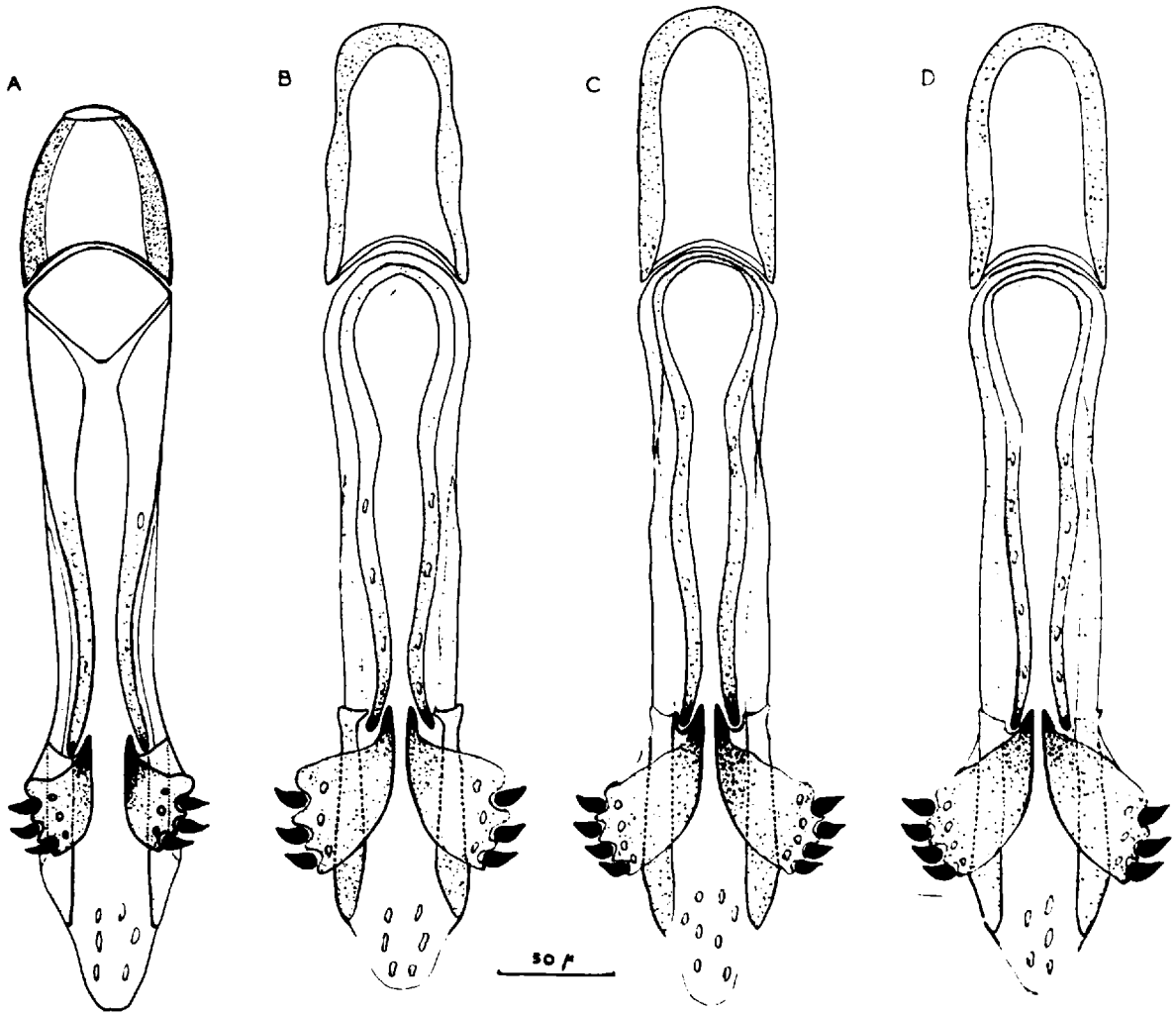


Fig. 56. Genitalia of: A, Telenomus truncatus Mayr; B,C,D, T. sokolovi Mayr; B, common; C, very rare; D, rare

brownish-yellow; flagellum deep brown. Scape four times longer than its greatest width. Pedicel brownish at base and brownish-yellow at apex; half as long as the first segment of flagellum; first and second segments of flagellum almost equal in length; twice as long as wide; third segment distinctly shorter than the first and second, but longer than the fourth segment; segments 6 - 11 clearly longer than wide; apical segment conical, as long as the third segment. Apical segment of tarsus deep brown.

Genitalia: (fig. 56).

Length: 1 - 1.2 mm

Females and males: Hants, Yateley, Cricket Hill, June and July 1965, 1966, bred from eggs of P. lituratus collected on gorse.

Female. Berks, Silwood Park, June 1965, one specimen beaten from broom (probably overwintered).

Host: P. lituratus in the field.

Bred in the laboratory from eggs of A. acuminata, E. integriceps, N. pusilla, P. lituratus, P. prasina and a few specimens from P. bidens.

This species parasitised batches of eggs of E. integriceps, and to a less extent those of P. bidens placed in the open at Yateley, June and July 1965.

Conclusion:

The following conclusions were drawn from the present work on the taxonomy of Asolcus and Telenomus spp:-

1) The identification of these egg parasites should be based on a large number of specimens, preferably from different hosts and localities.

2) There appeared to be a close similarity in some characters among several species of both genera; moreover one species was intermediate between the two genera.

3) Within certain limits variation in colour and in size appeared in the populations of several species; these characters however, remained constant in some species when they were reared on a variety of hosts and under different breeding and food conditions.

4) A combination of comparative biology with morphology was found to be satisfactory in determination of the true status of the closely related species.

5) During the course of this study it became evident that the identification and descriptions of certain species of these and of several other egg parasites of Pentatomoidea of both genera Asolcus and Telenomus were uncertain, i.e. some

species were found to be synonymous, while several others were identified as one species (see also Masner (1958) Delucchi (1961) Viktorov (1964) and Voegelé (1965)). This presumably has occurred because the taxonomy of most of the described species has been based only on the characters of dead specimens. Although this method of identification can be applied to some species, it repeatedly results in misidentification of the closely related ones.

6) It is desirable that a revision of other species of similar scelionids of the genera Asolcus and Telenomus should be made in which the identification of the parasites would be based on the combination of morphology and biological criteria.

7) All the six British scelionid species collected and described were new to Britain. Four Asolcus species appeared to be previously undescribed, whereas the two Telenomus species were accepted as already known species.

8) A new method of rearing these telenomid parasites was devised and a new host for rearing them throughout the year in the laboratory was found.

9) It is suggested that more study should be made on these parasites, not only because several species seems to be promising for biological control of some pentatomoid pests, but also because they are very interesting biologically.

THE BIOLOGY AND ECOLOGY OF EGG PARASITES COMPLEX OF BRITISH PENTATOMOIDEA

Asolcus waloffae sp.n.

A) Adults. (see page 225).

B) Morphology of the Immature Stages.

The morphology of the immature stages in Telenomus ullyeti Nixon has been described by Jones (1937); in Asolcus basalis by Kamal (1937) and Voegelé (1962 and 1964); in Hadronotus ajax by Schell (1943); in T. gifuensis Ashmead by Hidaka (1958); in Allophanurus indicus Subba Rao and Chacko by Subba Rao and Chacko (1961) and in Moroccan spp. of Asolcus by Voegelé (1964). The following is a description of morphology of the immature stages in Asolcus waloffae sp.n.

Egg (fig. 57):-

The newly deposited egg is almost transparent, oval, and with a long pedicel. Its size varies between 0.075 mm and 0.12 mm in length, and from 0.036 mm to 0.094 mm in width. The length of the pedicel is almost that of the egg body.

First Instar Larva (fig. 57):-

The first instar larva is teleaform (Clausen 1940) and pale white. Like the egg, the newly formed larva appears to be almost transparent and can be seen by transmitted light. The body size a few hours after emergence, is approximately 0.19 mm in length and 0.082 mm in width. At this stage the head and

abdomen are well defined, whereas the thorax is not.

The head is slightly curved, bearing a pair of distinct, sharply curved, needle-shaped mandibles, under which the mouth opening and the labium are placed.

The abdomen is long and curved, bearing a long appendage at its end, between which is a short spinous process. The long appendage is curved anteriorly, its tip directed towards the base of the mandibles. Surrounding the anterior part of the abdomen is a girdle of approximately 33 setae; the ends of these setae are directed posteriorly.

Second Instar Larva:-

The second instar larva is sacciform and flattened. It is similar to the third instar but differs from it in the size of the mandibles and that of the body. Its size is about 0.58 mm in length and 0.32 mm in width, and is grayish-white. The duration of this instar is shorter than that of the others.

Third Instar Larva:-

The third or final instar larva is hymenopteriform. The body is almost cylindrical, smoky-white and opaque, about 0.98 mm in length and 0.42 mm in width when it is mature. The head is followed by twelve to thirteen visible segments. At the end of this instar the larva occupies the whole space of the

host egg. Each mandible bears a single curved tooth.

Pupa:-

The morphological characters of the pupa are shown in fig. 57. At first the pupa is entirely white, but gradually darkens to black. A reddish colour soon appears in the compound eyes but that in the legs or male antennae appears in the late pupal period. The average size of the pupa is 0.93 mm in length and 0.40 mm in width.

C) Reproductive organs.

a) Female Reproductive Organs (fig. 57):-

These are composed of a pair of ovaries, each having seven polytrophic ovarioles. The two ovaries unite together and form the common oviduct which ends in the vagina. A small double bulbed spermatheca opens into the vagina near its opening into the ovipositor. The female genitalia are mostly chitinous; composed of a pair of inner valvula plates; each plate is connected to one fulcrum and ends in a sharp and heavily chitinised drilling position. The ovipositor lies between these inner plates. Both the inner plates and the ovipositor lie within in a chitinised outer valvula plate.

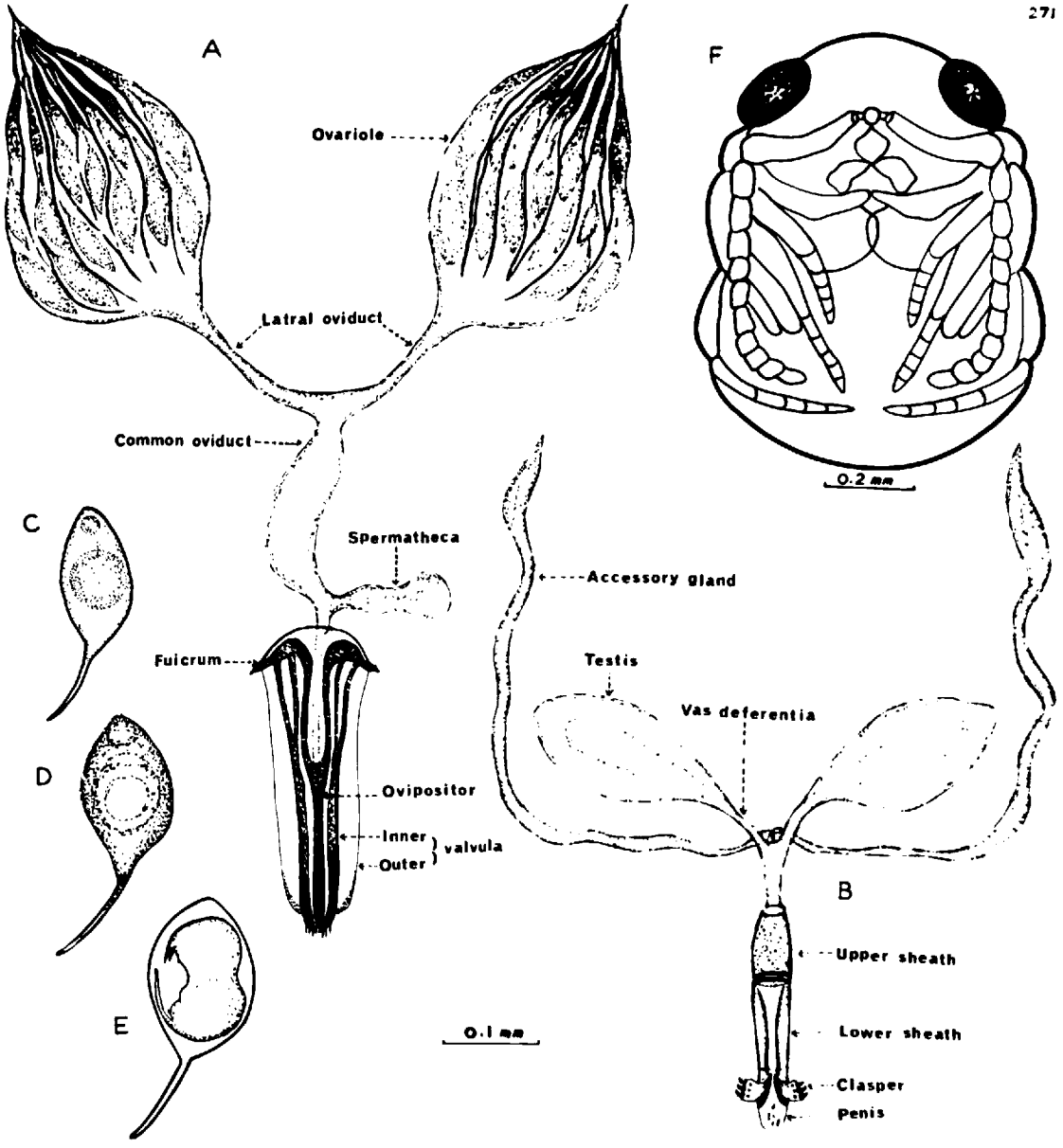


Fig. 57. Asolcus waloffae sp.n.: A, female, B, male reproductive organs; C, D, E, embryonic development; F, ventral view of pupa.

b) Male Reproductive Organs (fig. 57):-

These are composed of a pair of ovoid testes with short vasa deferentia which unite and enlarge to form the common ejaculatory duct. Each testis is enclosed in a double membranous sac. A pair of long tubular accessary glands open into the vasa deferentia before they unite.

The male genitalia (fig. 46) consist of a cylindrical tube through the middle of which runs the ductus ejaculatorius, ending in the penis. This tube is covered by upper and lower sheaths. The upper sheath is chitinised posteriorly and membranous anteriorly. This is joined to the lower one by a membrane which can be easily separated. The lower sheath has dorso-lateral chitinous thickenings and can be seen as a cylinder laterally. A pair of symmetrical claspers, each bearing three stout and heavily chitinised teeth, are attached to the anterior chitinous ribs which are joined to the lower sheath medially.

D) Mating:-

Mating in Trissolcus simoni Mayr has been described by Voukassovitch (1927); in Asolcus basalis Woollaston by Wilson (1961) and Cumber (1964) and in A. grandis and A. semistriatus Nees by Voegelé (1961) and Safavi (1963). The

following is a description of mating behaviour in A. waloffae which is a more detailed account than any found in the literature previously.

The males normally emerge before the females. On emergence the first male takes possession of the egg-batch and patrols it while standing on top, or on the edge of the eggs. It frequently examines the eggs one by one mostly the operculum and attacks any other males which may approach the batch of eggs. During the emergence of a female the male approaches the emergence aperture and increases the frequency of the antennal palpation touching the antennae and the head of the female. Although the activity of the male increases enormously at this time it rarely moves a few millimetres away from that egg until the female emerges completely. When females failed to emerge completely the males were found to pull them out by clasping the thorax of the females with their front legs.

Immediately after the emergence of the female, the male became even more active and mounted the female. It vibrated its antennae rapidly trying to touch those of the female which are usually bent under the head. The female may stop, or carry the male on her dorsum while making several attempts to shake him off. These attempts however are evaded

by the male which clasps the female abdomen firmly with hind and middle pairs of legs. Finally the female responds to the male and straightens its antennae against those of the male. The male then repeatedly and gently strokes the antennae, particularly the clubs, of the female, with the flagellum of his own antennae. Soon the female signals by means of extending its oviposition thus enabling the male to copulate. This is an important biological character exhibited by the females.

In all crossing tests, the female extended her ovipositor when the male was of her own species. The ovipositor is slightly curved upwards when extended, the aedeagus facing upwards being closed to the end of her closed wings. At that moment the male moves backwards to the posterior end of the female, flexes its abdomen slightly and extends his genitalia which are somewhat curved ventrally. The male aedeagus then touches the ovipositor and moves under it to insert the penis into the genital opening of the female. The duration of copulation varies from five to fifty-five seconds during which both sexes remain almost motionless; the male antennae may vibrate against those of the female. The male may also move its wings up and down several times during mating.

Soon after copulation the female withdraws her ovipositor and the male its genitalia; the male dismounts and remains calm for a few seconds. The female leaves the egg mass and remains nearby cleaning her body mostly with the front and hind pairs of legs. The legs have comb shaped hairs between the tibiae and first tarsal segments.

After a brief pause the male returns to the female and tries to repeat the mating, but the female does not respond. The female mates only once in her life. The male however returns to the egg mass waiting and examining the eggs until another female emerges to repeat the above process.

Virgin females have been observed to reproduce parthenogenetically, but they were found to mate even after this oviposition.

The male is capable of fertilising over twenty females in his life but in all cases a higher frequency of mating on the first two to three days of its life has been observed. The male also reacts in the same way towards an emerging male but after copulation it seems to recognise the other males and may drive them away from the egg-batch by trying to bite the newly emerged males. A number of males kept together however behaved in a manner similar to that shown to females.

E) Oviposition:-

Oviposition in A. basalis has been described by Kamal (1938) Wilson (1961) and Cumber (1964); in A. mitsukurii Ashmead by Hokyo and Kiritani (1966). The following is a description of oviposition behaviour in A. waloffae which is a more detailed account than found in the literature previously

Oviposition begins 2 - 3 days after emergence. Dissections of newly emerged females indicated that this pre-oviposition period was necessary for the complete development of the eggs. The gravid females show a very characteristic behaviour when parasitising their hosts.

1) Host Finding:-

During the day and particularly when the temperature rises above 20°C the females become very active and they run or fly up and down vibrating their antennae rapidly in front and searching for the host eggs. When a female approaches an egg mass and is about five millimetres away from it the frequency of the palpation drops. It appears "to be aware" of the presence of the host as indicated by the slow tapping of the antennae on the area around the egg mass. Then she moves towards the nearest egg. At this time the vibration of antennae increase once again and the female mounts the egg mass.

2) Rotating and Drumming:-

On mounting an egg mass, she becomes very active and normally walks over several eggs while palpating the opercula of the eggs. As the female antennae are clavate and the last six segments form a flattened and slightly curved club, this appears to enable the female to drum the convex surface of the host egg more efficiently. On examining an egg the female rotates on the operculum while palpating rapidly. This rotating movement is usually repeated two to five times. Then the lateral parts of the host egg are carefully examined. The female usually examines the whole of the exposed surface of the host egg, but she may examine only the lateral or the upper surface. Fresh and unparasitised eggs are generally used for oviposition but occasionally old, parasitised eggs, as well as the empty shells of the host eggs, have been laid in. This occurred when there was a shortage of host eggs or when the female had not laid in the first half of her life.

3) The Order in which the Eggs are Selected:-

After finding a suitable egg mass, the female would choose one egg to oviposit. The first could be any one from the egg mass. None of the observed females selected eggs in a particular order. Diagram 58 shows the irregularity of selection by two females. Occasionally the female chose an

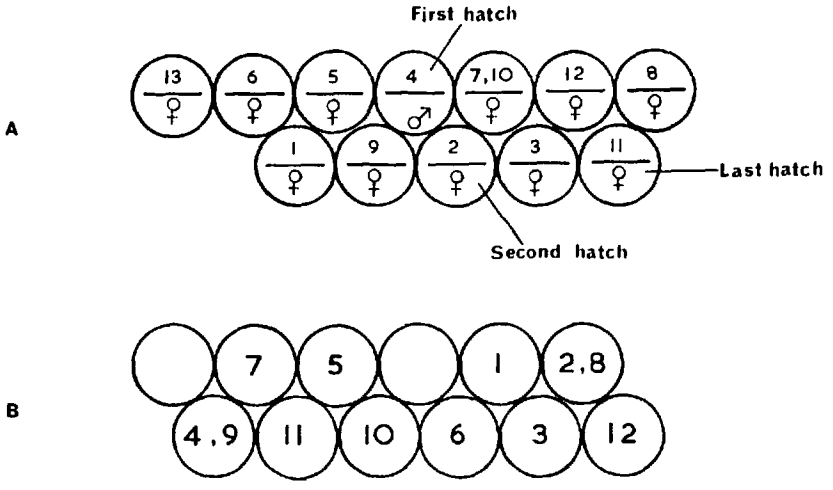


Fig.58. Tne order in which Hosts were selected during Oviposition and the Sex Ratio of Asolcus waloffae sp.n. on Eggs of Aelia acuminata (L.)

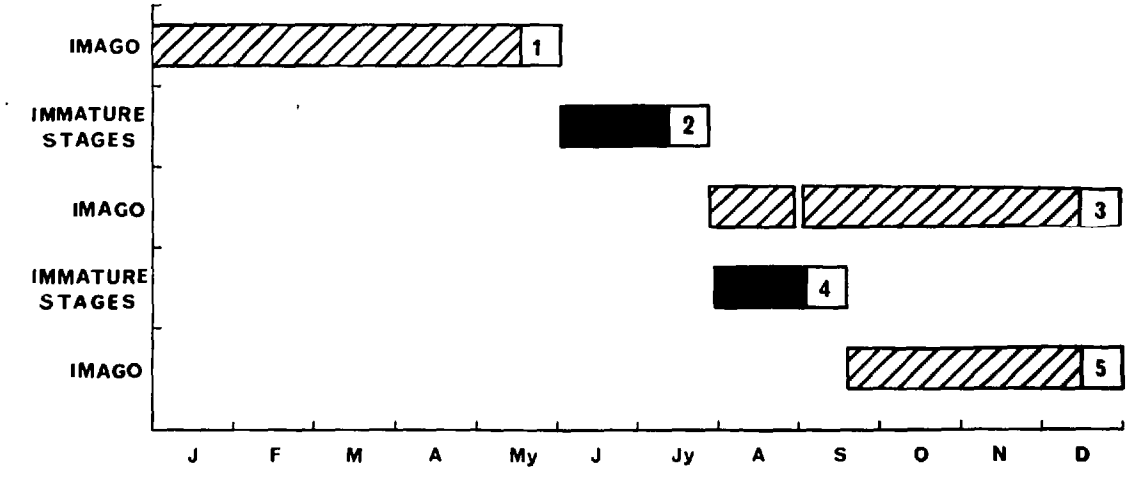


Fig.59. Life history of Asolcus waloffae sp.n. in 1965

1. Period of hibernation of females
2. Black blocks 2 and 4 depict the 1st and 2nd generations
3. Stencilled blocks 3 and 5 depict the adult periods of these generations

already parasitised egg. This mostly occurred when the female failed to mark the eggs after oviposition. Only rarely did the female accept the eggs which had been oviposited in and marked (Diagram 58).

4) The Site of Oviposition:-

The eggs of A. acuminata are barrel-shaped each mass consisting of 12 eggs placed in two rows. Whereas in Neottiglossa pusilla in which the eggs are slightly round (fig. 40, 60), there are 10 eggs in two rows. The parasite usually prefers to lay on the lateral surface of the host egg (see Table 28), but she may also oviposit on the top just below the operculum. When the egg mass was in three rows the inner row was usually parasitised on top while the two outer rows laterally. The wasps never layed through the operculum. When attempts were made to lay through the operculum, they were never successful, probably because the wasps were unable to pierce the opercula.

5) Drilling and Ovipositing:-

Once the host egg as well as the site of oviposition on it is chosen, the female leaves the egg, rotating its head half way away from it. She then moves backwards extending her ovipositor until it contacts the host between two adjacent eggs or on the surface of the egg on which she oviposits

later. She may probe around with her ovipositor a number of times until she finds a suitable point for penetration. This is carried out by clasping the egg with the hind as well as with the middle pairs of legs. The anterior pair of legs may assist in this action.

The drilling begins immediately by a "piston like" movement of the body muscles for several minutes until the hole for insertion is bored. This is done by the sharp end of the two heavily sclerotised ovipositor valvula plates which hold the ovipositor with them (fig. 57). Soon after the chorion of the host egg is punctured the female inserts the ovipositor into the host egg and releases an egg into the yolk just near the chorion and then withdraws the ovipositor. From the beginning of the drilling until the end of oviposition the flagellum of the antennae bend rhythmically corresponding to the muscle movement. The wings are normally half spread out or closed parallelto the abdomen. The period required for successful drilling and oviposition lasts between three to five minutes with a minimum of two minutes and 12 seconds and a maximum of 14 minutes and 32 seconds (see Table 28).

Table 28.

Time taken in oviposition behaviour by A. waloffae on A. acuminata in one day.

No. of female	No. of parasitised egg	Time required for a successful oviposition of each egg.					
		Examination		Drilling and oviposition		Marking	Site of oviposition
		Minute	Second	Minute	Second	Second	
1	1	3	7	7	15	20	bottom
	2	1	22	5	7	32	"
	3	1	12	14	32	44	top
	4	1	34	5	24	28	lateral
	5	0	48	12	28	32	top
	6	1	36	10	12	26	lateral
	7	1	50	7	48	36	"
	8	0	56	8	12	27	"
	9	1	12	10	24	31	top
	10	5	6	9	10	22	bottom
	11	4	16	12	34	43	"
	12	8	5	12	0	18	lateral
	13	0	59	9	25	23	"
	Total and average	2	46	9	53	29.3	Bottom 30.7% Lateral 46.2% Top 23.1%

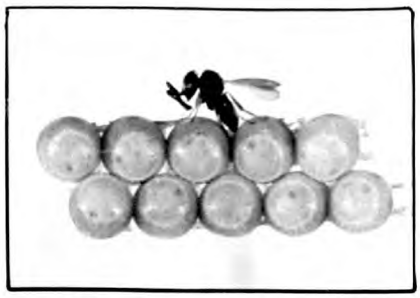
Table28(continued)

No. of female	No. of parasitised egg	Time required for successful oviposition of each egg.					
		Examination		Drilling and		Marking	Site of oviposition
		Minute	Second	Minute	Second	Second	
2	1	0	14	3	28	22	bottom
	2	0	20	3	12	8	top
	3	0	38	2	20	12	bottom
	4	0	52	2	42	15	lateral
	5	0	47	2	46	8	bottom
	6	0	36	3	8	7	top
	7	1	2	3	12	5	bottom
	8	1	24	3	26	9	top
	9	1	36	3	52	11	bottom
	10	1	20	2	44	10	bottom
	11	2	14	3	17	8	lateral
	12	2	24	3	31	6	top
	Total and average	1	11	3	13	10.08	Bottom 50% Lateral 17% Top 33%
3	1	1	1	2	12	12	Bottom
	2	0	22	3	8	14	"
	3	0	34	3	12	13	lateral
	4	0	39	4	2	12	top
	Total and average	0	65	3	12	12.75	Bottom 50% Lateral 25% Top 25%

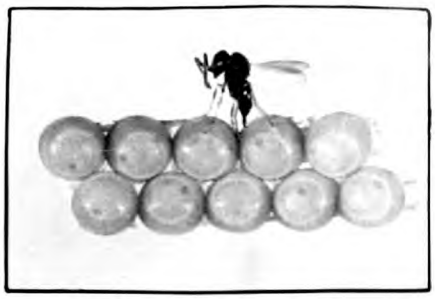
6) Marking of the Parasitised Eggs:-

The marking of the host eggs follows soon after each successful oviposition. When the female withdraws her ovipositor from the host egg, she lifts the body often releasing the anterior legs and is now supported by the hind and middle legs. She then waves the ovipositor to and fro across the egg surface frequently bringing the tip of the ovipositor in contact with the egg surface. Meanwhile a colourless substance is exuded by the ovipositor and is dabbed on the lateral and opercular surfaces of the host egg. The marking normally lasts about 25 seconds during which the female rotates its abdomen three to five times while the tip of the ovipositor is still in contact with the host.

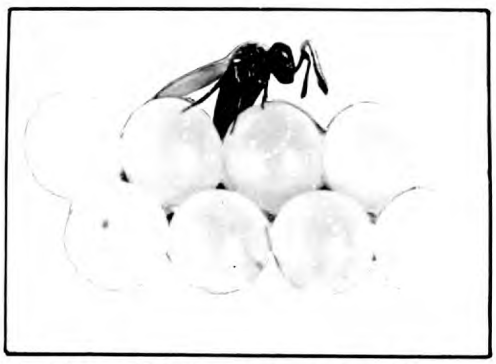
The marking was always seen only after a successful oviposition. This was confirmed by dissecting a large number of parasitised eggs. Marking of an adjacent egg when disturbed, or by mistake was only rarely seen. On such occasions the female was found to oviposit more than once in the same egg. On one occasion an egg was parasitised four times but only one parasite developed. When the host egg was superparasitised, only a single parasite developed and sometimes none.



A. waloffae sp.n. ovipositing in eggs of N. pusilla

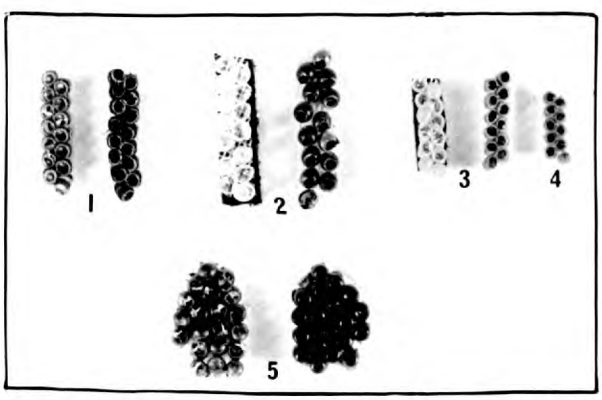


A. waloffae sp.n. marking its host after oviposition

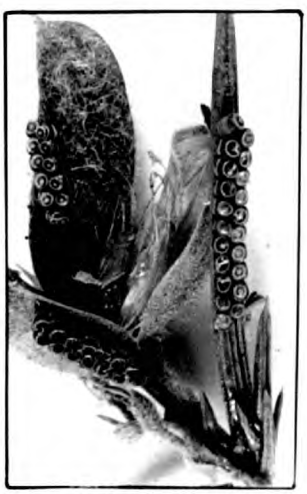


A. silwoodensis sp.n. ovipositing in eggs of E. integriceps

A. davatchii sp.n. hatching from the eggs of P. bidens



Parasitised (coloured) and unparasitised egg batches of: 1. Piezodorus 2. Eurygaster 3. Aelia 4. Neottiglossa 5. Picromerus



Parasitised (bottom) and unparasitised batches of P. lituratus eggs on gorse

Fig. 60. OVIPOSITION, MARKING AND HATCHING OF BRITISH Asolcus AND THEIR HOSTS

7) Resting and Daily Capacity for Oviposition:-

A gravid female usually continues ovipositing until all the developed eggs within the ovarioles are released. Normally the number of eggs deposited in a day is between 12 - 14 but this varies in different females and in one female it reached 49. After several ovipositions the female tends to have a resting period, on or beside the host egg mass, when the body is kept horizontally with the antennae bent over her head.

Oviposition, however, may be induced by some stimuli such as light, mechanical movement or the approach of another female and continue until all the developed eggs have been laid. Later, the female rests beside the egg mass or moves under the surface on which the host eggs are laid. The pause between two successive ovipositions of 12 or 14 eggs may last for several days, depending on the temperature and the food which seems to be important for egg development.

F) Development.

The development durations of each stage have been determined by regular dissecting and are shown in Table 29. The parasites were bred on the eggs of Aelia acuminata; Neottiglossa pusilla and Eurygaster integriceps at 20°C and 28°C with 75% relative humidity.

Table 29.

Immature stages	Duration of stage in days			
	20°C		28°C	
	Male	Female	Male	Female
Egg	2	2	1	1
1st instar	3	4	1.5	2
2nd instar	2	2	1	1
3rd instar	4	5	2	3
Pupa	11	12	5.5	6
Total	22	25	11	13

Development of Embryo and Larvae at 28°C.

The newly deposited eggs were found in the yolk of the host egg close to the point of penetration of the ovipositor through the chorion. The development begins soon after the egg is laid and the parasite egg floats freely on the fluid of the host egg. During the incubation period the oily droplets in the yolk aggregate as two circular regions, the large one occupying a greater part of the egg and the small one near to the oval end (fig. 57). The egg gradually becomes round and after 10 to 12 hours the embryo could be seen through

the transparent membrane. About four to five hours later the embryo develops a caudal horn and the mandibles (fig.57). When the embryo is about 18 hours old the incubation period is almost complete and the first larval instar can be seen before it emerges at the oval end. The hatching is apparently caused by the movement of the mandibles which rupture the very thin membrane.

The first instar larva is telaeform with large curved mandibles. It is very active and moves the head and caudal horn up and down, probably by the use of the ventral and dorsal muscles which are almost invisible. The function of the setae around the anterior part of the abdomen is obscure. The movement of the larva decreases as it develops. After two days, the larva reaches its full size and moults to the second instar.

The second instar larva is sacciform and its duration is one day. The larva feeds on the rest of the contents of the egg and its size increases gradually. The movement decreases towards the end of this instar, the larva occupying most of the space of the host egg.

The third instar larva is hymenopteriform; at this stage all the body segments are visible. The mandibles are shorter than in the previous instar. The tracheal system appears in this instar and respiration is presumably carried out through it. When the larva reaches maturity it occupies the whole space of the host egg. At the end of this instar the last larval moult takes place by a rupture line which passes vertically along the head capsule, the white pupa appearing later.

The duration of the third instar is about three days and the larva shows very little movement at the end of this stage. The colour of the host egg usually changes from grayish-white to black at the end of this instar, the change of colour is due to a very thin membrane forming at this stage which had began its formation from the second instar; later the black membrane appears around the larva and almost touches the host chorion. When the parasites were bred at 28°C or 30°C in several cases the black membrane did not appear even during the pupal period. On such occasions the larva and particularly the pupa with the orange compound eyes were seen through the chorion of the host eggs.

The pupa (fig. 57) appeared after seven to eight days. The early pupa is entirely white being slightly convex dorsally and rather motionless. The compound eyes are pale orange but soon become orange or reddish. The head, thorax and later the abdomen and the clubs of antennae gradually change from white to gray and finally to black, after three days. The colour of other segments of female antennae and the male antennae, wing venation of both sexes change during the last stages of pupal development. The duration of the pupal stage is between five to six days.

G) The Emergence of the Adult Parasite:

Complete development from egg to adult takes 11 days in the case of males and 12 in the females. A wriggling movement takes place for a short while within the host egg rupturing the black membrane before emergence. Normally the head of the embryo and later the adult was found orientated towards the micropylar, or opercular end, but about 4% were found to be upside-down. Emergence of the adults usually occurred in the mornings. The adult first pierces a small hole in the centre of the operculum and this is gradually enlarged by chewing out crescent-shaped pieces along its edge in a circle. The mandibles help in chewing which is

continued until a hole large enough for the adult to emerge is formed (fig. 60). The emergence hole is usually completed in about an hour. At emergence, the antennae are first protruded, followed by the head and the first pair of legs over the edge of the opening. These aid the parasite to draw out the rest of its body and the wriggling movements of the first pair of legs help it to emerge.

In a few cases, emergence has been seen from the base of the host egg. This perhaps indicates that the embryo has developed upside down. A series of the freshly laid host egg masses were placed upside down on the strips of cardboard, the operculum being fixed on a piece of bees' wax. These were parasitised by the females. Emergence, however, was still orientated towards the operculum, showing that the development did take place upside down.

When these egg masses were in two rows emergence took place from the sides which were exposed. However, when they occurred in three or more rows the parasites within the inner rows were unable to emerge completely and died with their heads protruding from the unexposed sides. It is possible that the operculum helps in respiration during the development of the parasite. It must be noted, however, that under natural conditions, the micropyle or opercular end normally faces upwards and outwards.

H) Biological Characteristics of Asolcuswaloffae sp.n.

Life history.

1. Occurrence in the Field:-

The overwintered females appear in the field about the time the first Aelia acuminata and Neottiglossa pusilla eggs are deposited. The earliest record is of the parasite collected by sweeping among grasses in the North Gravel at Silwood Park on the 3rd June, 1965. The latest emergence of the parasite in the same season was on the 14th September, after two generations on the eggs of A. acuminata had been completed. More female parasites were collected in July on the North Gravel and the Heath (fig. 36) as well as at Cricket Hill in Yateley (Hampshire). The males were very rare in the field and only one specimen was collected on the 29th July, 1965.

During the warm sunny days in July the females run or fly rapidly up and down on the leaves, stems and ears of grasses while they are searching for the hosts. They feed on honey dew, juices of plants and nectar of flowers such as the Rubus spp.

2. Number of Generations:-

In order to follow the life cycle of the parasite large numbers of host eggs were placed in the field between the grasses, at the beginning of the period of oviposition of Aelia acuminata. After two weeks the eggs were collected and transferred to the rearing cages in the field within the same habitat. Observations were made on alternate days until the development of the parasites was completed and the adults had emerged. The females of the first generation were provided with the host eggs which were about 3 - 5 days old. Similar egg masses were also placed in the field to investigate the occurrence of the next generation in the natural habitat. In this way two successive generations were found to occur at Silwood Park in 1965. Diagram (fig. 59) illustrates the life cycle of A. waloffae.

The parasites were fed on honey dew produced by some aphids within the rearing cages. The male parasites of the first generation lived until the 1st week of October and those of the second generation until the middle of November. The females within the cages usually laid most of their eggs and died by the end of August, but those which did not oviposit aestivated and later hibernated within the breeding cages under

the bushes. Most of the parasites however died and only 3% of the females survived the winter. The females of the second generation appeared in the first week of September, their life cycle was the same as that of the first generation females and only 5 per cent survived until next spring. All the females fed on 5% sugar solution or on pollen died during the winter, whereas the survivors usually fed on honey dew.

3. Effects of the hosts and food on the Longevity and Fecundity of Asolcus waloffae sp.n.

A study was made of the effects of different food and of host species on the longevity and fecundity of A. waloffae. Three following experiments were carried out at 28°C and 75% relative humidity. Each replicate consisted of a pair of parasites bred in the field and fed on honey dew for three days before the experiment. The experiments were carried out in No. 1 rearing boxes.

Experiment No. 1:-

The diet consisted of honey and 3% sucrose solution with A. acuminata eggs as hosts (see Table 30).

Experiment No. 2:-

The diet consisted of the honey with water only with A. acuminata eggs as hosts (see Table 31).

Experiment No. 1

Table 30. Breeding of *A. waloffae* on eggs of *A. acuminata* (host one day old) and on the diet of honey and 3% sucrose solution.

Pairs of parasites (replicates)	Longevity of the parasites in days		No. of host eggs supplied to parasites		No. of parasitised host eggs					% Parasitism
					Parasites emerged		Parasites not emerged		Total	
	Male	Female	Batch	Eggs	Male	Female	Male	Female		
1	24	29	7	92	13	75	0	0	88	95.7
2	16	24	8	98	10	60	2	3	75	76.5
3	21	25	8	95	15	72	0	3	90	94.7
4	20	28	9	101	18	54	1	1	74	73.3
5	22	26	8	91	22	61	2	3	88	96.7
Total and Average	20.6	26.4	8	95.4	15.6	64.4	1	2	83	87.0

Experiment No. 2.

Table 31. Breeding of A. waloffae on eggs of A. acuminata (host two days old) on the diet of honey with water.

Pairs of parasites (replicates)	Longevity of the parasites in days		No. of host eggs supplied to parasites		No. of parasitised host eggs					
					Parasites emerged		Parasites not emerged		Total	% Parasitism
	Male	Female	Batch	Eggs	Male	Female	Male	Female		
1	12	16	8	88	10	24	6	3	43	48.9
2	17	31	8	84	1	14	0	6	21	25.0
3	14	23	8	72	21	20	0	0	41	56.9
4	10	13	8	82	2	10	0	0	12	14.6
5	19	21	7	78	6	34	0	0	40	51.3
Total and Average	14.4	20.8	7.8	80.8	8	20.4	1.2	1.8	31.4	38.8

Experiment No. 3

Table 32. Breeding of *A. waloffae* on eggs of *E. integriceps* (host two days old) and on the diet of honey and 3% sucrose solution.

Pairs of parasites (replicates)	Longevity of parasites in days		No. of host eggs supplied to parasites		No. of parasitised host eggs					% Parasitism
					Parasites emerged		Parasites not emerged		Total	
	Male	Female	Batch	Eggs	Male	Female	Male	Female		
1	19	34	8	106	0	1	1	3	5	4.7
2	16	27	7	96	0	5	0	0	5	5.4
3	14	44	9	108	0	1	0	0	1	0.9
4	18	39	8	98	0	12	0	0	12	12.2
5	15	37	10	102	0	0	1	4	5	4.9
Total and Average	16.4	36.2	8.4	102	0	3.8	0.4	1.4	5.6	5.5

Experiment No. 3:-

The diet consisted of honey and 3% sucrose solution with E. integriceps eggs as hosts (see Table 32).

In the first experiment the longevity of the male was 20.6 and that of the female 26.4 days. On the average 87.0per.cent of the presented host eggs were parasitised by a female wasp. In the second experiment the longevity of the male and female were 14.4 and 20.8 days respectively, and parasitism of the host eggs dropped to 38.9 per cent. In the third experiment the longevity of the male and that of the female was 16.4 and 36.2 days respectively and the percentage parasitism had dropped sharply to 5.5per cent of the host eggs.

The above results indicate that the food as well as the host had an effect on longevity and fecundity of the parasite. In experiment No. 3 the longevity of the male had decreased unexpectedly. It is probable that the males used in this experiment would have mated with more females than in experiment No. 1. The use of 3% sucrose solution indicated a decrease in the longevity and fecundity in experiment No. 1 and No. 2, but it must be noted that this decrease of parasitism from 87.0% to 38.9% is also due to the change in the host. The females usually preferred fresh eggs, but they also did accept hosts which were not too old.

The results of experiment 3 show that the female longevity had increased as was expected but oviposition decreased and the percentage of parasitised host eggs had sharply decreased to 5.5%. This shows that the eggs of E. integriceps used in this experiment were unsuitable for this parasite and that A. waloffae sp.n. is selective in its choice of host. The females in experiment No. 3 survived much longer than those in No. 1 which had the same diet but had laid significantly higher humbers of eggs. Therefore, as could be expected, longevity decreased as fecundity increased.

4. Parthenogenesis:

The females laid parthenogenetically the resulting progeny always being males. Among all the females collected in the field and tested in the laboratory a single female was found to produce males only. This indicated that in nature parthenogenesis occurs very rarely.

Sex Ratio and Factors Influencing the Sex of the Parasites:

The sex ratio of the parasites emerging from the egg masses collected in the field and of those bred in the laboratory was recorded. The ratio of males to females was 1 : 4. From each batch of 12 or 10 host eggs at least one male had emerged; the males normally emerged before the females

(see diagram 58). The females usually leave the egg mass soon after emergence and the males mostly patrol or live near the egg masses until their death.

In the field the females would be fertilised, unless the male possessing the egg mass is somehow driven away from it before the emergence of the females (e.g. by a strong wind or rain, birds, man etc.); in these cases the females may be fertilised by anyother male of her own species.

Virgin females produce only males and fertilised females produce both sexes with a higher ratio of females.

In the laboratory an experiment was carried out to find when the eggs were fertilised by the sperm stored within the female. This was done by presenting the fertilised females with host eggs at different time intervals after copulation. The egg masses were sketched and the eggs numbered. Then the females were allowed to oviposit and the order in which the eggs were parasitised was recorded (see diagram 58). After the first three parasites emerged the rest of the eggs were dissected and the sex of the parasites was recorded. Preliminary investigations indicated that:-

1) The newly mated female produced only males.

2) The sex ratio of parasites became 1 male : 1 female about 1 day after mating at 25°C and 75%.

3) The sex ratio changed to about 1 male : 4 females after three days.

4) There was a tendency to produce males in the early and in the late stages of oviposition on a single egg mass, although occasionally males were produced in the middle of an oviposition period.

5. Host Specificity:

Asolcus waloffae sp.n. is an egg-parasite of Pentatomoidea. In the field it was collected from the eggs of Aelia acuminata and Neottiglossa pusilla. Several thousands of eggs of Piezodorus lituratus, Eurygaster integriceps and Picromerus bidens were placed in the field, where the female of A. waloffae was collected and were not parasitised by this species of Asolcus.

In the laboratory A. waloffae parasitised and emerged from the first two mentioned hosts but all attempts to breed it on the eggs of P. bidens were unsuccessful. It failed to parasitise host eggs when they were old and the host embryos were formed.

6. Distribution:

A. waloffae was collected in Silwood Park and Yateley (Hampshire). Thus so far it is known only from southern England.

Asolcus davatchii sp.n.

A) Adult.(see page 231).

B) Morphology of Immature Stages:

Egg.(fig. 61):

The newly deposited egg is transparent, oval, and with a pedicel shorter than the egg. The size of egg varying between 0.082 mm to 0.15 mm in length, and from 0.043 to 0.098 mm in width.

First Instar Larva (fig. 61):

The first instar larva is teleaform, pale white and transparent. Its body size one day after hatching is about 0.22 mm in length and 0.093 mm in width. Like the previous species, the head and abdomen are well defined, whereas the thorax is not. It has a pair of distinct sharply curved, needle-shaped mandibles, under which are the mouth opening and the labium. The abdomen is long, bearing a long appendage at its end, between which is a short spinous process. At the end of this instar the abdomen grows much longer (fig. 61) and a sac-like tube from the mouth to the end of the abdomen becomes faintly visible. This probably is the digestive organ and is divided into two narrow tubes near the mouth parts. Surrounding the anterior part of the abdomen is a girdle formed of about 34 setae, their ends being directed posteriorly.

Second Instar Larva:

The second instar larva is sacciform and is greatly different from the previous one. It is similar to the third instar. Its size is approximately 0.66 mm in length and 0.43 mm in width, the colour being grayish-white.

Third Instar Larva (fig. 62):

The third and last instar larva is hymenopteriform. The colour of the body is smoky-white and opaque; it is about 0.96 to one mm in length and 0.48 to 0.56 mm in width at the end of this instar. The head is followed by thirteen visible segments. The larva occupies the whole space of the host egg at the end of this instar. It has a pair of curved mandibles, eavh bearing a sharp needle-shape tooth.

Pupa:

The morphological characters of the pupa are shown in fig. 62, C, D, E. The colouration of the pupa is white after moulting but it gradually darkens to black by the end of the pupal period. The orange or reddish colour of the compound eyes appears soon but that of the legs and of the antennae appears only in the late pupal period. The size of the pupa is 0.97 to 0.99 mm in length and 0.46 to 0.51 mm in width.

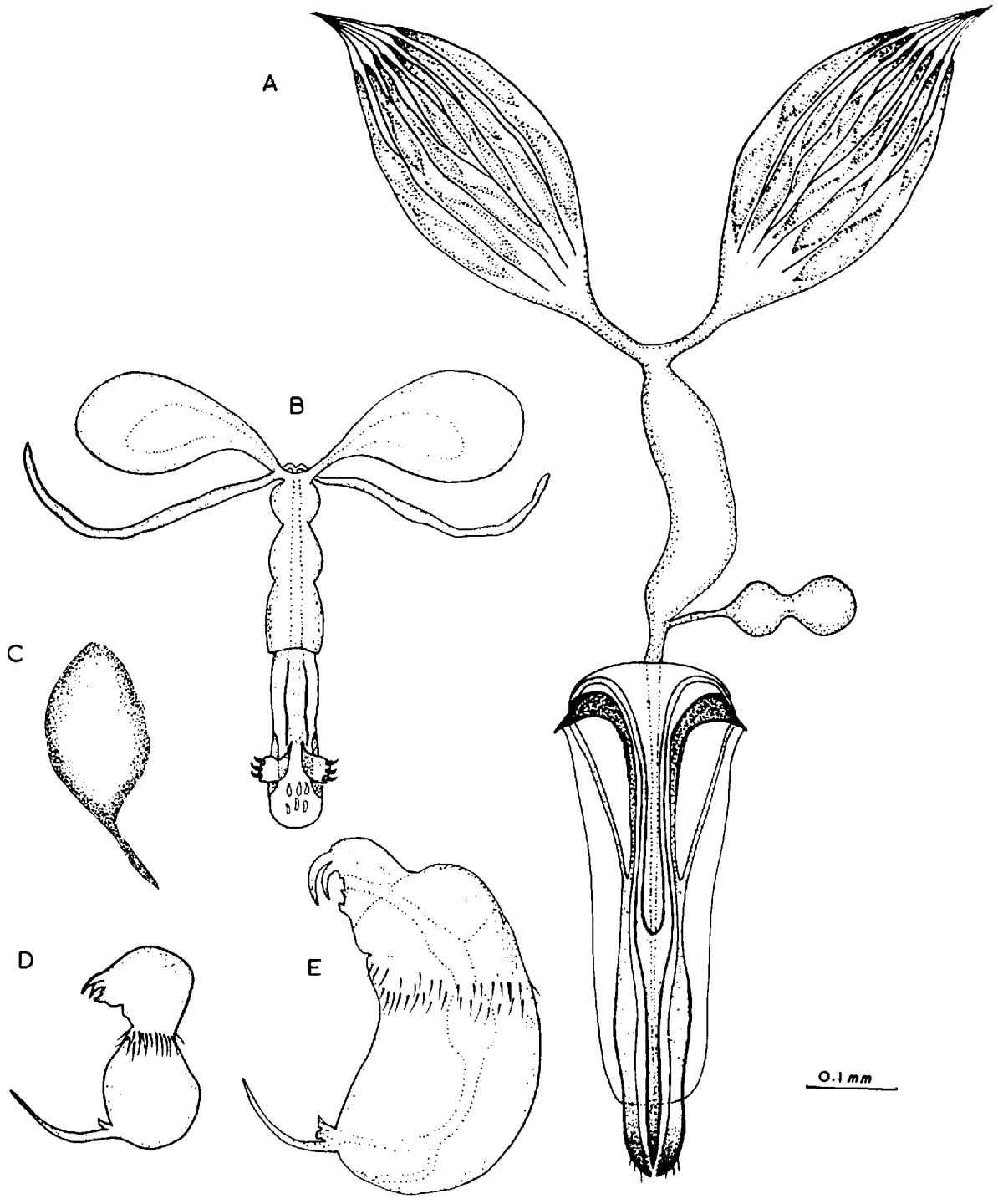


Fig. 61. **Asolcus davatchii** sp.n. : A, female ; B, male reproductive organs ; C, egg ; D, newly and E, mature first instar larvae.

C) Reproductive Organs.

a) Female Reproductive Organs (fig. 61):

These are composed of a pair of ovaries, each having seven polytrophic ovarioles. The size of each ovariole is slightly longer than A. waloffae. The two ovaries unite together and form the common oviduct which ends in the vagina. A small double bulbed spermatheca opens into the vagina near its junction with the ovipositor. The female genitalia are composed of a pair of inner chitinous valvula plates; each plate is connected to one fulcrum and ends in a sharp and heavily chitinised drilling portion, the ovipositor being chitinised and ending in a acute heavily chitinised screw. This lies between the inner plates. Both the ovipositor and the inner plates lie within a chitinised outer valvula plate.

b) Male Reproductive Organs (fig. 61):

These are composed of a pair of ovoid testes with short vasa deferentia which unite and enlarge to form the common ejaculatory duct. Each testis is enclosed in a double membranous sac, the outer one being almost transparent. The tubular accessary glands are shorter than those of the other British Asolcus. These glands open into the vasa deferentia. The male genitalia (fig. 46) consist of a

cylindrical tube through the middle of which runs the ductus ejaculatorius ending in the penis. The length and the width of the genitalia are greater than those of A. waloffae, the upper and lower sheaths also differ from the above species. These sheathes are joined by a membrane dorsally. The upper sheath is mostly chitinised, whereas in the lower sheath the two claspers, the end part of the ribs, as well as a small part of the lateral portion enclosing the lower sheathes and penis, are chitinised. The two claspers are symmetrical each bearing three stout and heavily chitinised teeth. The claspers are attached to the anterior chitinous ribs which are joined to the lower sheath medially, their ends which bear the teeth being free and able to move easily.

D) Mating:

This was found to be similar to that of the previous species. In 1965 and 1966 mating occurred in the field during August and September. In the field the males usually emerged four to eight days before the females. On 26. 8. 65 the first male was observed to emerge from a parasitised egg mass of Palomena prasina at Silwood Park. This egg mass was parasitised in the laboratory on 28. 5. 65 and was placed in

the large rearing cage (fig. 37) in the field on the following day. Emergence occurred in the morning. Soon after cleaning the body and wings, the male started to examine the eggs one by one. This examination was continued frequently during the sunny and warm hours of day, every three to five minutes. The egg mass contained 28 eggs which were in four rows, each of seven eggs. Two other males emerged later on 2. 9. 65; both were driven off immediately from the egg mass by the first male, which was patrolling it. On 3. 9. 65 the first female emerged in the morning from one of the outer eggs. Mating occurred immediately in a manner similar to that described for A. waloffae. This was repeated with 23 other females that emerged gradually until 12. 9. 65. The possessor male actively patrolled the egg mass for the first half of its life, and was never observed to move away from it more than about three centimetres, even after all the females had emerged. The male was frequently seen to examine the inner space of empty chorions by means of its antennae. No feeding was seen but his activity decreased towards the end of September to a noticeable degree. Later, the male mostly rested beside the egg mass and then died on 13.10.65.

In the laboratory, all attempts to cross this species with A. semistriatus, A. grandis, the three species of

British Asolcus and the two of Telenomus were unsuccessful. A number of males of A. davatchii and A. grandis kept together were found to behave in a manner similar to that of the females i.e. some allowed males to mount them.

E) Oviposition:

The oviposition behaviour in A. davatchii was similar to that of A. waloffae, the main difference was in the oviposition stance involving the position of the wings which was found to be characteristic of the species. In A. davatchii the wings are held almost verically at right angles to the body and well away from the surface.

The order in which the eggs are selected is irregular as in the previous species. Diagram 63 shows the irregularity of selection shown by two females. In this diagram one of the eggs in batch (A) was parasitised twice by the same female. The average period of examination lasted 67 seconds, with a minimum of 11 seconds and a maximum of one minute and 20 seconds (see table 33). The time taken for drilling and oviposition was four minutes and 14 seconds on average, with a minimum of two minutes and 47 seconds and a maximum of six minutes and 24 seconds. The average duration

Table 33.

Time taken in oviposition behaviour by one *A. davatchii* on *P. bidens* eggs in one day.

No. of parasitised egg	Time required for a successful oviposition of each egg.						
	Examination		Drilling and oviposition		Marking	Site of oviposition	Position of the wings
	Minute	Second	Minute	Second	Second		
1	1	12	4	02	56	bottom	open
2	0	38	3	02	43	"	"
3	0	23	3	52	38	"	"
4	0	16	4	02	18	"	"
5	0	19	2	47	31	"	"
6	0	16	3	20	36	"	"
7	0	11	3	21	16	"	"
8	0	15	3	37	22	"	"
9	0	28	3	52	-	top	"
10	0	53	4	14	35	bottom	"
11	0	48	3	12	42	"	"
12	1	02	5	28	24	top	closed
13	1	05	4	35	70	bottom	open
14	0	48	5	30	46	top	"
15	0	54	5	02	37	bottom	"
16	1	20	6	24	24	top	"
Total and Average	0	67	4	14	33.6	bottom 75% top 25%	open 93.75% closed 06.25%

of marking was 33.62 seconds, with a minimum of 16 seconds and a maximum of 70 seconds; one egg was not marked although it was parasitised. The oviposition site on the outer eggs was at the bottom and on the top just below the operculum, on the inner eggs. In one egg the attempts to oviposit through the operculum were unsuccessful and then the female moved her ovipositor and placed it below the operculum.

F) Development:

The duration of the developmental period in each stage has been determined by regular dissection and these durations are shown in table 34 . The parasites were bred on the eggs of Picromerus bidens; Palomena prasina and of Eurygaster integriceps at 20°C and 28°C at 75% relative humidity.

Table 34.

Different Immature Stages	Duration of stage in days			
	20°C		28°C	
	male	female	male	female
Egg	5	5	2	2
1st instar	7	8	4	5
2nd instar	5	6	2.5	3
3rd instar	11	13	5.5	6
pupa	27	31	15	16
Total	55	63	29	32

Development of Embryo and Immature Stages at 28°C:

The period of developmental stages of A. davatchii was found to be quite different to that of all the five British as well as other known non-British egg-parasites of Pentatomoidea. The embryonic development in the yolk was similar to that in the previous species, but the period required for this development was twice as long at 28°C, and more than twice at 20°C. After two days the incubation period was completed and the first instar larva hatched. This larva was very active in the first half of its development. It was frequently seen to move its head and caudal horn up and down. This movement decreased towards the end of its development. Then the larva moulted through a rupture in the head region to the second instar, which was sacciform and completely different from the first stage.

The duration of the second instar was short; its size increased distinctly by the end of this stage and it occupied most of the host egg.

The third instar was hymenopteriform (fig. 62) and appeared through a vertical rupture in the head of the previous instar. At this instar the segments of the body were easily distinguished and the tracheal system was visible. The duration of this instar was longer than that of the previous

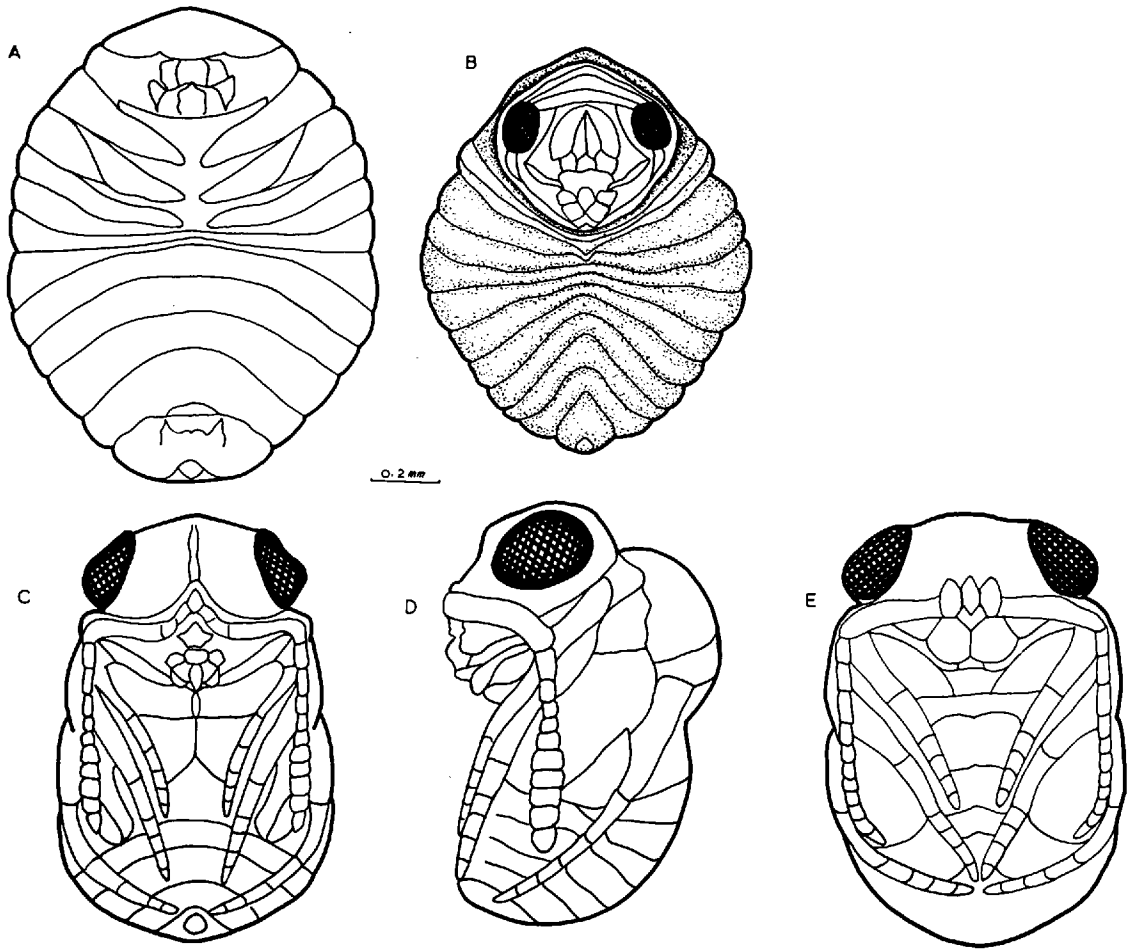


Fig. 62. *Asolcus davatchii* sp.n.: A, third instar larva; B, emergence of pupa from third instar larva; C, D, ventral and lateral aspects of pupa, ♀; E, pupa, ventral, ♂.

stages; at the end of the third instar the larva occupied almost the whole space within the host egg.

At the end of this instar the colour of the larva was grayish and it moulted (fig. 62) through a rupture line that passed vertically on the head capsule when the white pupa appeared. The duration of the third instar was five and a half days for males and six days for females. At the end of this stage the colour of the host changed to black as has been described for A. waloffae.

Pupation occurred after 14 days in the male and 16 days in the female. The early pupa was entirely white being somewhat convex dorsally (fig. 62). It showed very little movement. The orange, or reddish colour of the compound eyes appeared in the early pupal period but the black colour of the body was formed after about 10 days at this stage. The reddish colour of the legs and that of the antennae appeared after 25 days in the males and 28 days in the females. The wings also formed at the end of the pupal period. This long period of development is unknown in the other species of the genus Asolcus. Neither is this prolonged development known in any species of Telenomus that parasitise the eggs of Pentatomoidea.

G) The Emergence of the Adult Parasite:

After the complete development from egg to adult the parasites emerged from their hosts in a manner similar to that described in A. waloffae from the eggs of P. prasina and E. integriceps. When P. bidens was the host, the time required to make the emergence rupture was much longer than from any other host eggs. Probably this was related to the greater thickness of the chorion and particularly of the operculum of P. bidens eggs; (see fig. 60).

H) Biological Characteristics of Asolcus davatchii sp.n.

Life history

1) Occurrence in the Field:

The overwintered females of this very rare British species usually appeared at the time of oviposition of Palomena prasina. The wasps were collected by beating broom in the Heath and on Gunnes's Hill at Silwood Park during June and July 1964 and 1965. Two females were collected by sweeping grass at Silwood and Yateley in July 1965. All the wasps were collected on warm and sunny days and in the field one of its hosts was P. prasina.

2) Number of Generations:

At the beginning of the oviposition period of P. prasina, 10 egg masses of this pentatomid and of P.

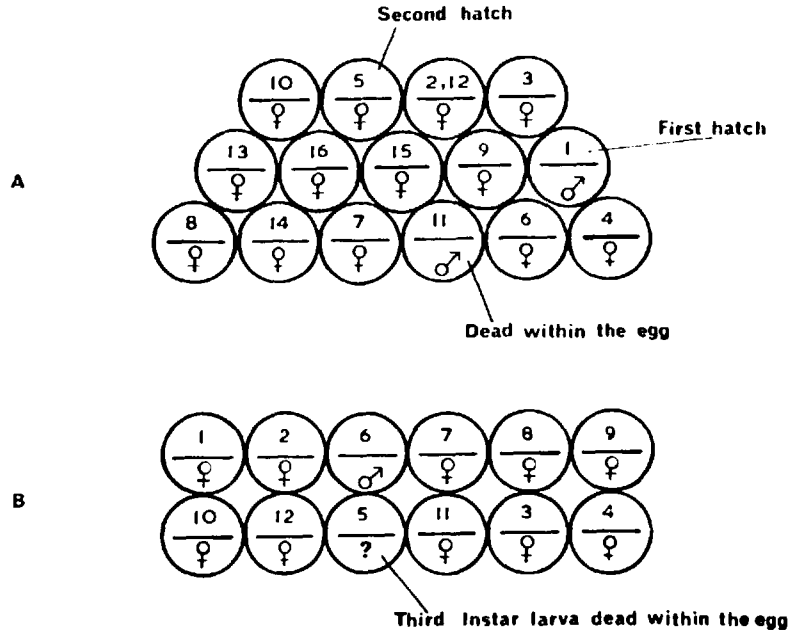


Fig.63. The order in which Hosts were selected during Oviposition and the Sex Ratio of Asolcus davatchii sp.n. on Eggs of Picromerus bidens (L.)

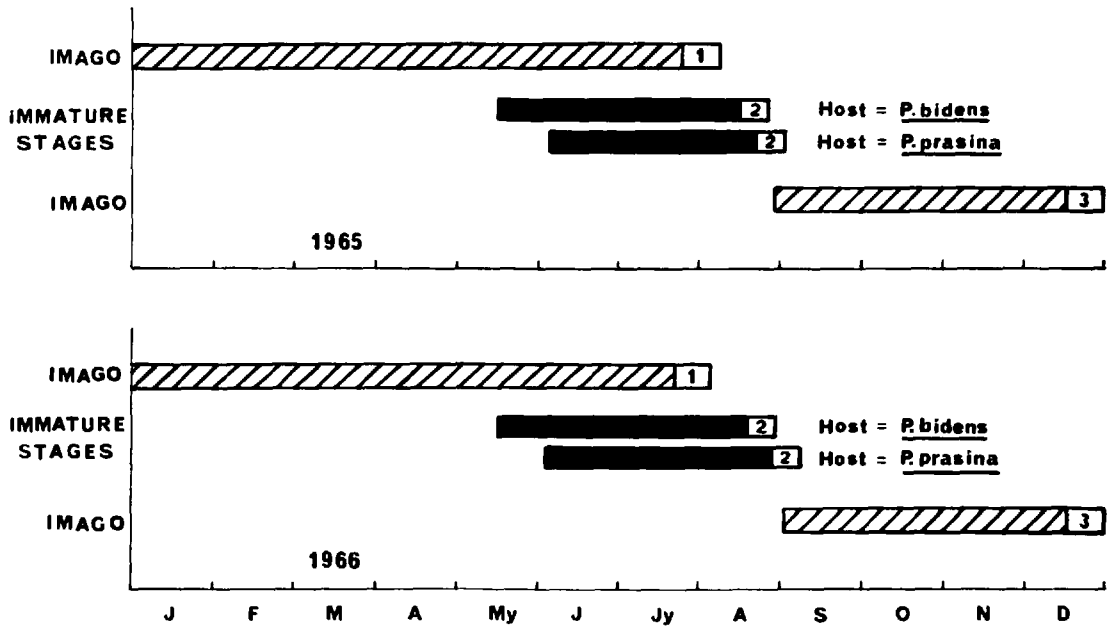


Fig.64. Life history of Asolcus davatchii sp.n. in 1965 and 1966

1. Period of hibernation of females
2. Black blocks 2 depict the Ist generation
3. Stencilled block 3 depicts the adult period of the generation

bidens together with several females of A. davatchii were introduced into the field rearing cages. They were placed within the large field cages (see p. 205) at Silwood. As a check, simultaneously several egg masses of P. bidens parasitised in the laboratory were also transferred into the large field cages at the end of April 1965 and in mid and late May in 1966. This proved a suitable means of studying the development and voltinism of this Asolcus species which appears to be highly host specific. Several thousands of egg masses of P. bidens, P. lituratus, Aelia acuminata and E. integriceps were placed in the field and examined later, but none was parasitised by A. davatchii, although this experiment was carried out in the locality and at the time when this wasp was found in the field.

Diagram 64 illustrates the life cycle of A. davatchii in two seasons. According to this diagram only one generation of this Asolcus occurred in 1965 and 1966. The duration of development of immature stages was approximately three months.

As has been described before, the adult parasites were fed on honey dew. In 1965 all males died by the end of October and only 4 per cent of the females

survived until the following spring. The females which were fed on 5% sugar solution, or on pollen, died by the end of December.

3) Effect of the Hosts and Food on the Longevity and Fecundity of Asolcus davatchii sp.n.

These experiments were carried out in the No. 1 rearing cages. The parasites were fed on different diets of honey dew, sugar solution or pollen, for three to four days before the experiments. Eggs of P. bidens and E. integriceps, were provided as hosts and rearing took place at 20°C and 28°C.

Experiment No. 1:

The diet consisted of 5% sucrose solution with P. bidens as host. The host eggs were stored for 15 days at 2 - 3°C in a refrigerator before being supplied to the parasites. The results of this experiment are shown in Table 35 , and indicate that the females lived longer than the males, that they parasitised 39.4 per cent of the host eggs offered to them (i.e. 30 out of 70 eggs) and that the sex ratio of the offspring (males to females) was approximately 1 : 6.

Experiment No. 2:

This experiment was carried out to study the fecundity and longevity of A. davatchii upon the old eggs of Picromerus bidens. These eggs were about five months old and

Table 35.

Longevity and Fecundity of A. davatchii breeding on P. bidens eggs, at 20°C. Diet 5% sucrose solution, hosts about 20 days old, kept at 2-3°C

Pairs number (replicates)	Longevity in days		No. of eggs supplied to parasites	No. of eggs parasitised				Total of parasitised eggs	No. of bugs larva emerged	% parasitism
				Parasites hatched		Parasites not hatched				
	Male	Female		Male	Female	Male	Female			
1	22	28	96	1	22	-	10	33	41	34.4
2	18	24	59	1	2	1	6	10	3	16.9
3	15	33	84	1	15	2	23	41	17	48.8
4	20	27	100	2	28	-	18	48	36	48.0
5	17	12	72	2	18	1	16	37	20	51.4
6	11	18	50	2	23	3	6	34	11	68.0
7	15	9	82	1	6	-	3	10	56	12.2
8	14	22	70	3	16	1	4	24	32	34.3
9	19	17	80	1	16	4	30	51	13	63.7
10	26	29	66	4	24	1	9	38	9	57.5
11	21	13	86	1	4	-	1	6	36	6.9
12	29	18	62	16	-	3	-	19	0	30.6
13	21	31	108	2	23	4	15	44	16	40.7
14	12	26	100	5	23	6	4	38	6	38.0
15	14	21	106	4	29	2	8	43	14	40.5
16	27	33	80	2	14	-	6	22	2	27.5
17	26	20	70	3	9	3	17	32	19	45.7
18	20	16	66	4	10	1	13	28	10	42.4
19	28	34	84	1	5	1	19	26	17	30.9
20	24	26	50	1	12	1	13	27	8	54.0
21	19	28	80	14	-	8	-	22	22	27.5
22	15	29	50	1	7	1	14	23	6	46.0
Total and Average	19.7	23.4	77.3	3.3	13.90	1.95	10.6	29.8	17.9	38.55

kept at 2 - 3°C before being supplied to the parasites. The diet was of honey and water and the food was provided to the parasites throughout their lives. The experiment was carried out at 20°C and 75% relative humidity. In each replicate a pair of parasites bred at 25°C and fed for three to five days were used. The results are shown in Table 36 and indicate that either the age of host eggs or the diet had considerable effect on the parasites. The diet obviously prolonged the lives of both the males and the females, but the fecundity of the females was greatly affected either by it or by the age of the host eggs.

Experiment No. 3:

This experiment was carried out to study the interspecific competition between two species of egg parasites Asolcus davatchii and A. silwoodensis sp.n. The diet consisted of honey and water with E. integriceps as host. In each replicate one female of each parasite, bred at 25°C and fed for four to five days was used. The batches of the host egg were provided to the parasites daily during the first ten days of the experiment. The host eggs were about five to 10 days old and were kept at 2 - 3°C before being supplied to the parasites. The experiment was repeated at 28°C and 75% relative humidity. The results are shown in Table 37.

Table 36.

Fecundity and Longevity of *Asolcus davatchii* sp.n. upon the five months old *Picromerus bidens* eggs at 20°C.

Pairs number	Longevity in days		No. of eggs supplied to parasites	No. of eggs parasitised				Total of parasitised eggs	% parasitis
				Parasites hatched		Parasites not hatched			
	Male	Female		M.	F.	M.	F.		
1	35	124	70	0	0	0	0	0	0
2	14	122	66	0	0	0	0	0	0
3	16	69	84	0	0	0	0	0	0
4	24	15	74	0	0	0	0	0	0
5	32	16	80	0	0	0	0	0	0
6	40	127	82	0	0	0	0	0	0
7	38	101	78	0	0	0	0	0	0
8	45	92	60	0	0	0	0	0	0
9	29	91	76	0	0	0	0	0	0
10	55	106	82	0	0	0	0	0	0
11	12	132	64	0	0	0	0	0	0
12	32	127	78	2	2	0	1	5	6.4
13	23	28	54	0	0	0	0	0	0
14	34	79	86	0	0	0	0	0	0
15	56	82	70	0	0	0	0	0	0
16	31	71	76	0	0	0	0	0	0
17	15	100	74	0	0	0	0	0	0
18	27	57	78	0	0	0	0	0	0
19	17	14	86	0	0	0	0	0	0
20	49	63	84	0	0	0	0	0	0
Total and Average	31.20	80.8	75.10	0.10	0.10	0	0.05	0.25	0.33

It can be seen that again on this diet the females of A. davatchii lived a long life, but failed to oviposit. A. silwoodensis had a shorter life span but on the average parasitised 75 out of the 109 eggs presented to it.

Originally it was hoped to see whether the two species of Asolcus compete, but since A. davatchii on this diet failed to oviposit, when it alone was present (see expt. 2) no conclusions could be drawn.

However, it is obvious that under these experimental conditions A. silwoodensis laid a large number of eggs.

Parthenogenesis:

The females were able to lay parthenogenetically the resulting progeny always being males. All the females collected in the field and tested in the laboratory produced both sexes. This indicated that in nature the females were always fertilised.

Sex Ratio and Factors Influencing the Sex of the Parasites:

This was similar to that in the previous species the ratio of males to females being 1 : 5. Frequently two males emerged from each batch of about 14 eggs (see diagram 63). Virgin females produced only males and fertilised females

Table 37.

Interspecific competition between the two parasites *Asolcus davatchii* sp.n. and *A. silwoodensis* sp.n. on eggs of *E. integriceps* at 28°C

No. of replicate	Longevity of the parasites in days		No. of eggs supplied to parasites		No. of eggs parasitised								No. of eggs parasitised by A.davatchii		No. of eggs parasitised by A.silwoodensis	
					Parasites hatched				Parasites not hatched							
	A.dava.	A.silw.	Batches	eggs	A.dava.		A.silw.		A.dava.		A.silw.		Total	% parasitism	Total	% parasitism
					M.	F.	M.	F.	M.	F.	M.	F.				
1	13	8	6	72	0	0	7	29	0	0	0	0	0	0	36	50.0
2	48	52	9	112	0	0	11	68	0	0	0	0	0	0	79	70.5
3	12	9	9	116	0	0	11	72	0	0	1	0	0	0	84	72.4
4	13	10	9	108	0	0	7	73	0	0	0	0	0	0	80	74.1
5	43	41	8	98	0	0	50	21	0	0	5	1	0	0	77	78.6
6	65	14	8	102	0	0	18	54	0	0	0	0	0	0	72	7 .6
7	86	29	10	132	0	0	24	92	0	0	1	1	0	0	118	89.4
8	84	51	8	94	0	0	10	58	0	0	1	0	0	0	69	73.4
9	20	47	10	124	0	0	33	65	0	0	1	2	0	0	101	81.5
10	30	13	8	106	4	5	12	0	1	3	0	0	13	12.26	12	11.3
11	79	32	8	98	0	0	12	12	0	0	0	0	0	0	24	24.5
12	68	48	8	100	0	0	17	30	0	0	0	2	0	0	49	49.0
13	52	26	10	136	0	0	16	104	0	0	0	1	0	0	121	89.0

Table 37. (continued)

No. of replicate	Longevity of the parasites in days		No. of eggs supplied to parasites		No. of eggs parasitised								No. of eggs parasitised by A. davatchii		No. of eggs parasitised by A. silwoodensis	
					Parasites hatched				Parasites not hatched							
	A.dava.	A.silw.	Batches	eggs	A.dava.		A.silw.		A.dava.		A.silw.		Total	% parasitism	Total	% parasitism
					M.	F.	M.	F.	M.	F.	M.	F.				
14	39	17	7	88	0	0	17	2	0	0	1	1	0	0	21	23.9
15	69	18	10	128	0	0	25	85	0	0	1	0	0	0	111	86.7
16	51	31	8	104	0	0	6	52	0	0	0	1	0	0	59	56.7
17	91	25	8	96	0	0	13	72	0	0	0	0	0	0	85	88.5
18	64	28	9	116	0	0	21	71	0	0	2	1	0	0	95	81.9
19	56	48	10	138	0	0	47	76	0	0	1	0	0	0	124	89.9
20	88	12	9	118	0	0	90	0	0	0	0	0	0	0	90	76.3
Total and Average	53.55	27.95	8.6	109.3	0.2	0.25	22.35	51.80	0.05	0.15	0.70	0.5	0.65	0.59	75.35	68.93

M. = Male F. = Female

A. dava. = A. davatchii A. silw. = A. silwoodensis

produced both sexes with higher ratio of females.

In the laboratory an experiment similar to that made on the previous species was carried out to find out when the eggs were fertilised by the sperm stored within the females. The resulting progeny showed a sex ratio similar to that in A. waloffae. However, in one batch the female produced a female in the early stages of its oviposition (see diagram 63).

Host specificity:

In the field Asolcus davatchii was collected from the eggs of Palomena prasina. Several thousands of eggs of A. acuminata, E. integriceps, P. lituratus and P. bidens were placed in the field in an area where the females of A. davatchii were collected but they remained unparasitised by this species of Asolcus.

In the laboratory A. davatchii parasitised and emerged from the eggs of E. integriceps on several occasions, but it was easily bred in large numbers from the eggs of P. bidens and P. prasina. It failed to parasitise the eggs of the pentatomoids mentioned above and also the eggs of its host when they were old or their embryos were already formed.

Distribution:

A. davatchii was collected in Silwood Park and Yateley (Hampshire). Thus so far it is known only from southern England.

Asolcus nixo-martini sp.n.

A) Adult: (see page 247)

B) Morphology of the Immature Stages:

The morphological characters of the immature stages of A. nixo-martini are shown in figs. 65, 66. They are similar to the immature and the adult stages but slightly smaller than those of A. silwoodensis.

C) The Alimentary Tract (fig. 65)

This consists of two sacs forming the fore and the hind-gut. These are connected by a rather narrow mid-gut. The fore-gut is very large compared with the other parts of the digestive system and is connected to the mouth parts by a narrow and long tube - the oesophagus. There are four narrow and long malpighian tubes which open into the alimentary canal near the junction of the fore and the mid-gut. The latter leads into a short rectum. The malpighian tubes are colourless whereas the intestines usually contain food and are opaque. In the other species of Asolcus and Telenomus examined, the alimentary canal was similar to that of A. nixo-martini.

D) Reproductive Organs:

a) Female:

The reproductive organs are illustrated in fig. 65. They consist of a pair of ovaries, each with seven

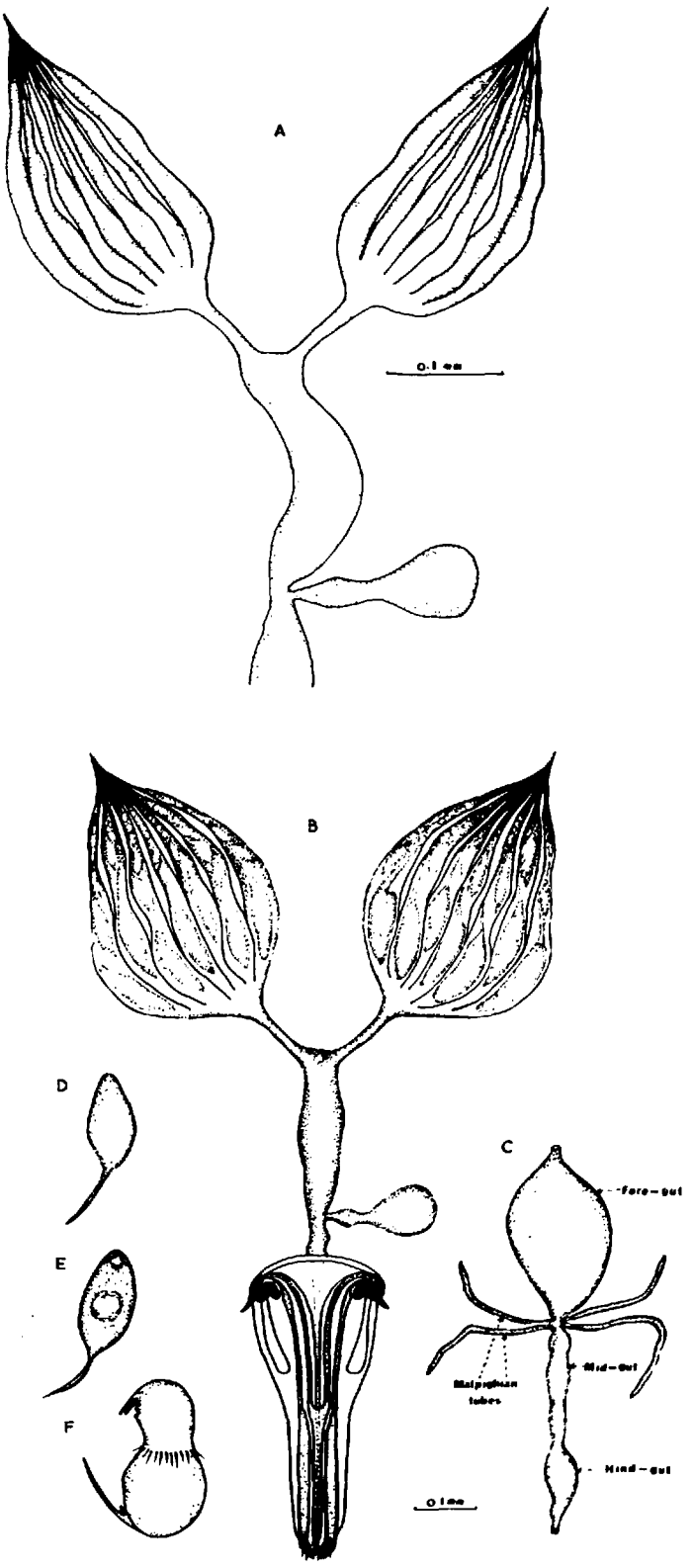


Fig 61 Asolcus nixo-martini sp.n.. A - PRE-MATURE OVARIES . B . FEMALE REPRODUCTIVE ORGANS WITH MATURE OVARIES . C - ALIMENTARY TRACT , D - NEWLY LAID EGG , E , EGG SHOWING EMBRIONIC DEVELOPMENT , F - FIRST INSTAR LARVA

polytrophic ovarioles. The common oviduct, the spermatheca and the rest of the internal genitalia are similar to those of the previously described species.

b) Male:

The internal male reproductive organs are illustrated in fig. 70. They are similar to those of A. silwoodensis. The external genitalia of the male are shown in fig. 51. They differ somewhat slightly from those of A. silwoodensis and the other Asolcus species in shape and in the degree of chitinisation. The external genitalia of this species are similar to those of A. grandis and A. semistriatus.

E) Mating:

In 1964, 1965 and 1966 mating occurred in the field during June, July and August. The process of copulation is similar to that in the previously described species. In the laboratory males and females behave similarly to A. silwoodensis. All attempts to cross this species with A. davatchii sp.n., A. grandis Thom. (Delucchi), A. semistriatus Ns (Delucchi), A. silwoodensis sp.n. and A. waloffae sp.n. were unsuccessful. A number of males of A. nixo-martini kept together, and also with the males of the other Asolcus species, behaved as females as did the previous species.

F) Oviposition:

The oviposition behaviour in A. nixo-martini was similar to that of A. waloffae. When the eggs were pierced laterally, the parasite kept its wings almost vertically but when the host egg was pierced from below the wings were only half open. The order in which the host eggs were selected was also random in this species, (Diagram 67) shows the irregularity of selection shown by three females. In batch C, although one host egg was parasitised three times by the same females, and two other host eggs twice each, only one parasite emerged from these superparasitised eggs. The parasite usually prefers to lay on the free part of the bottom and on the top of the host egg (see Table 38), but she may also oviposit laterally.

G) Development:

The developmental period of each stage is shown in Table 39. The parasites were bred on the eggs of Aelia acuminata, E. integriceps, P. bidens and P. lituratus at 20°C and at 28°C, at 75% relative humidity.

The developmental periods of immature stages are somewhat longer than in A. silwoodensis.

Table 38.

Time taken in oviposition behaviour by *A. nixo-martini* on *L. bifons* eggs in one day.

Selected females	No. of parasitised eggs	Time required for a successful oviposition of each egg.					
		Eamination		Drilling and oviposition		Marking	Site of Oviposition
		Minute	Second	Minute	Second	Second	
1	1	2	12	4	15	62	bottom
	2	1	54	5	45	47	top
	3	0	25	6	47	53	bottom
	4	0	18	5	38	18	"
	5	0	22	4	32	33	"
	6	0	27	4	48	12	"
	7	0	26	5	10	22	top
	8	0	19	4	30	25	bottom
	9	0	34	5	52	33	"
	10	0	23	4	47	46	"
	11	0	27	5	15	38	"
	12	0	34	4	52	43	"
	13	0	25	4	46	38	"
	14	2	14	3	20	38	"
Total and Average	14	0	49	5	02	36	bottom 85.7% top 14.3%
		Minute	Second	Minute	Second	Second	
2	1	1	14	4	36	11	top
	2	0	18	3	52	14	"
	3	0	22	3	28	15	"
	4	0	24	3	33	19	lateral
	5	0	14	3	17	15	top
	6	0	12	3	18	18	bottom
	7	0	09	3	47	20	"
	8	0	14	3	16	14	"
	9	0	16	3	28	32	"
	10	0	22	4	07	18	"
	11	0	19	4	28	22	"
	12	0	16	4	36	18	top
	13	0	48	3	54	16	"
	14	0	48	4	08	10	"
	15	0	56	4	18	16	"
Total and Average	15	0	27	3	09	17	bottom 40% lateral 6.7% top 53.3%

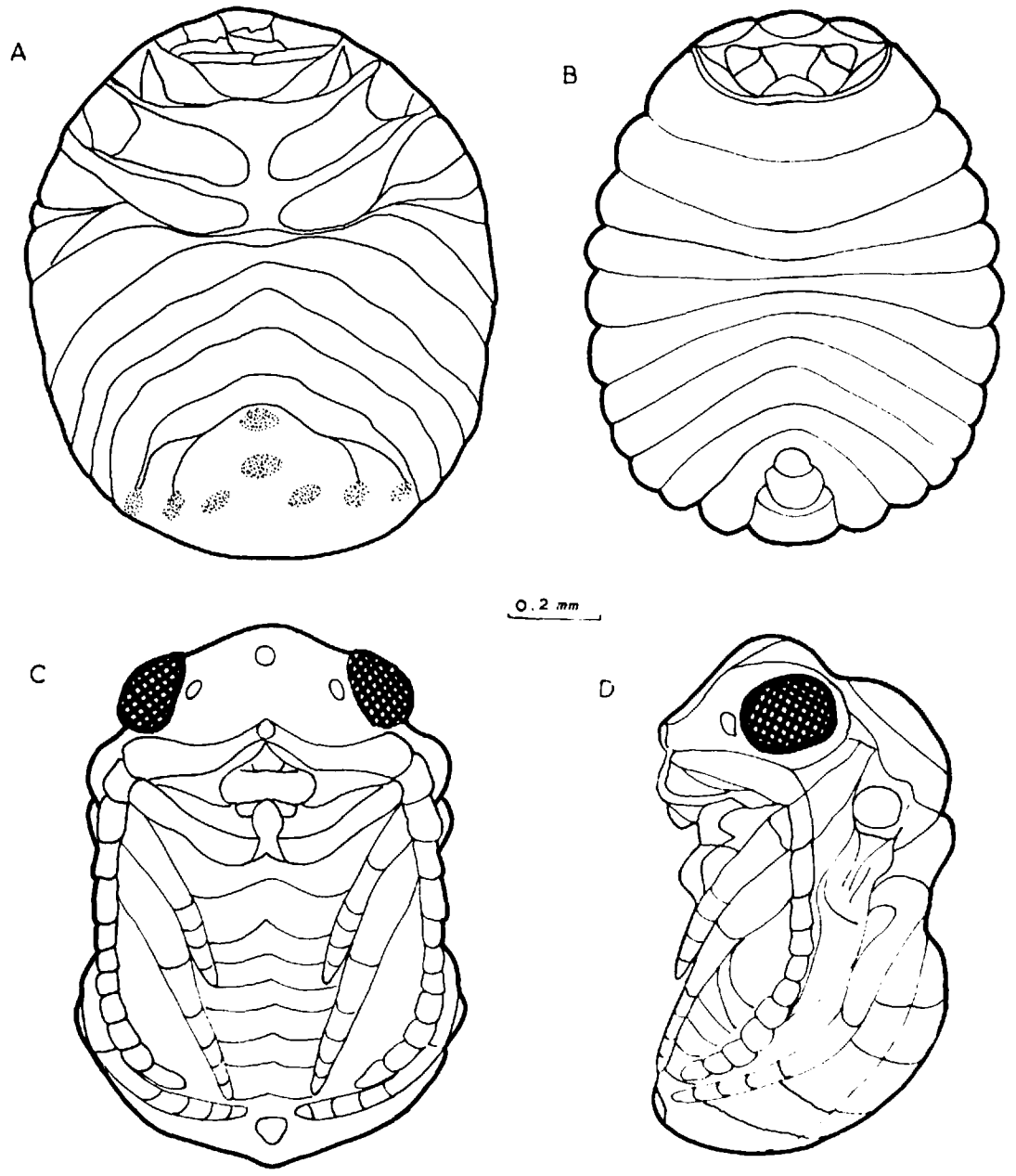


Fig. 66. A, B, **Ventral views of mature third instar larvae of:** A, Asolcus silwoodensis B, Asolcus nixo-martini sp.n.; C, **pupa, ventral** ♂; D, **lateral** ♀

Table 39. Developmental period of A. nixo-martini sp.n.

Immature stages	Duration of stages in days			
	20°C		28°C	
	Male	Female	Male	Female
Egg	2.0	2.0	1.0	1.0
1st instar	3.5	4.0	2.0	2.5
2nd instar	1.5	2.0	1.0	1.5
3rd instar	3.5	4.0	2.0	2.5
Pupa	9.0	11.5	5.0	6.0
Total	19.5	23.5	11.0	13.5

H) The emergence of the adult parasites:

The manner of emergence of the adults from the host eggs was very similar to that of A. silwoodensis.

I) Biological Characteristics of Asolcus nixo-martini sp.n.

a) Life history

1) Occurrence in the Field:

The overwintered females of this wasp usually appeared at the time of the oviposition period of P. lituratus in the field. The females were collected by beating broom at Silwood Park and at Yateley towards the end of May and during June in 1964, 1965 and 1966. Several females were also collected by sweeping grasses in the Heath, North and South

Gravel at Silwood and at Cricket Hill in Yateley during June and July 1965 and 1966. All the parasites were collected on warm and sunny days.

2) Number of Generations:

This was studied by the method described for A. silwoodensis. Diagram 68, illustrates the life cycle of A. nixo-martini in three seasons, and shows that this Asolcus sp. was trivoltine in 1964, 1965 and 1966. The parasites were fed on honey dew. In 1964 and 1965 all males died by early November and only 6per cent of females survived until next Spring. All the other females which were fed on other diets died during December and January.

3) Fecundity and Longevity at different temperatures.

Experiment No.1:

This experiment was carried out to study the fecundity and longevity of A. nixo-martini at various temperatures as high as 28°C and as low as 20°C. In each replicate a pair of parasites was used. These parasites were previously bred at 25°C. They were fed with honey and 5% sugar solution throughout their life. The females were supplied with the eggs of E. integriceps which were about three weeks old and previously kept at 2 - 3°C.

The results of these experiments are shown in Tables 40 and 41.

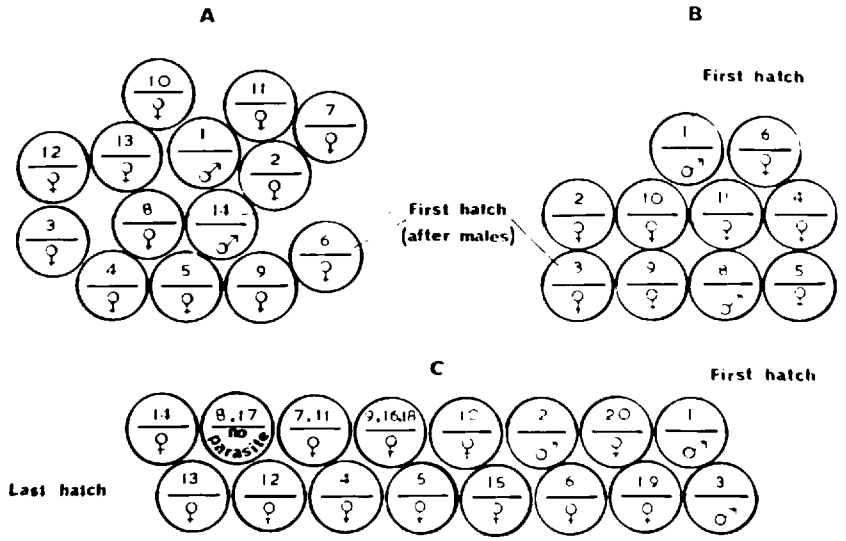


Fig. 67. The order in which Hosts were selected during Oviposition and the Sex Ratio of Asolcus nixo-martini sp.n. on Eggs of Picromerus bidens (L)

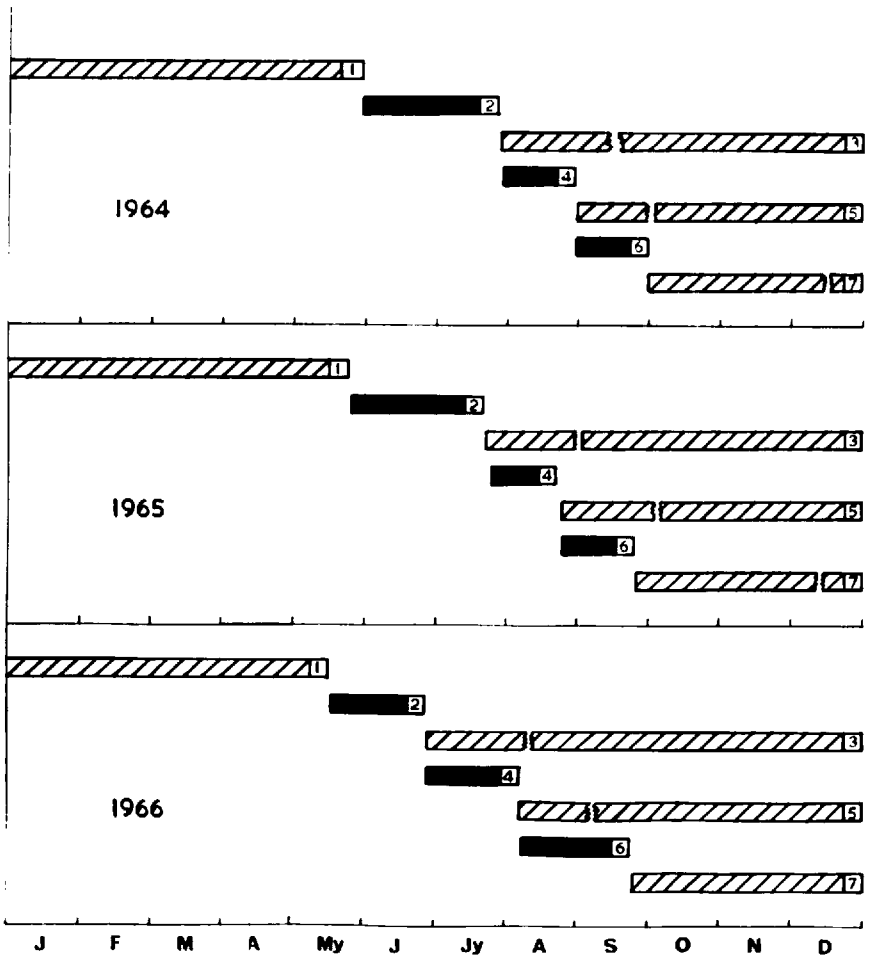


Fig. 68. Life history of Asolcus nixo-martini sp.n. in three seasons

1. Period of hiberration of females
2. Black blocks 2 4 and 6 depict the 1st, 2nd and 3rd generations
3. Stencilled blocks 3, 5 and 7 depict the adult periods of these generations

Table 40.

Fecundity of A. nixo-martini sp.n. breeding on E. integriceps eggs at 28°C and 75% R.H. Food honey and 5% sugar solution; host eggs three weeks old previously kept at 2 - 3°C

Pair Numbers (Replicate)	Longevity in days		No. of eggs supplied to parasites		No. of eggs parasitised				Total	% Parasitism
					Parasites hatched		Parasites not hatched			
	Male	Female	Batch	Eggs	Male	Female	Male	Female		
1	23	26	8	114	5	38	1	7	51	44.7
2	25	27	8	112	7	28	0	10	45	40.2
3	13	29	8	108	8	43	2	18	71	65.7
4	18	24	7	104	14	34	0	5	53	51.1
5	24	23	9	110	15	45	1	14	75	68.2
6	20	24	8	113	7	30	2	8	47	41.6
7	26	17	7	98	18	0	0	0	18	18.4
8	23	14	7	90	8	42	0	2	52	57.8
Total and Average	21.5	23	7.75	106.1	10.25	32.5	0.75	8.0	51.5	48.5

Table 41.
Breeding at 20°C

1	31	25	8	98	0	2	1	5	8	8.2
2	24	45	8	104	3	20	3	17	43	41.3
3	38	52	8	102	1	19	0	3	23	22.5
4	29	39	7	96	12	8	3	13	36	37.5
5	33	56	8	104	10	16	2	11	39	37.5
6	26	61	8	108	1	3	0	0	4	3.7
7	28	43	7	94	9	9	1	7	26	27.65
8	19	47	8	106	4	13	2	21	40	37.7
9	32	62	9	112	3	10	2	16	31	27.7
10	30	40	8	100	5	7	1	2	15	15.0
Total and Avergae	29	47	7.9	102.4	4.8	10.7	1.5	9.5	26.5	25.9

Parthenogenesis:

Similar to the previous Asolcus spp., the females were able to lay parthenogenetically, the resulting progeny always being males. All the females collected in the field and tested in the laboratory, produced both sexes except two females which were collected on 22.7.66 at Yateley, and which, for some unknown reason, did not lay. The females, however, were found to be fertilised in nature.

Sex Ratio and Factors Influencing the Sex of the Parasites:

Similar to that in the previous species, the ratio of males to females was 1 : 5. The number of males and females in each batch depended on the number of eggs in a single egg mass and the age of the ovipositing females. An experiment was carried out in the laboratory to determine the sex ratio of Asolcus nixo-martini. The parasites were previously bred on P. bidens eggs at 25°C and were fed on honey and water for three days before being used. The females were fertilised immediately after their emergence. The eggs of P. bidens were supplied to the parasites as host eggs and breeding took place in No. 1 design cages, at 28°C and 75% relative humidity. Fresh host eggs were provided to the

parasites soon after one egg mass was successfully parasitised; therefore the females had a chance to lay all their eggs in one day or on the next.

Table 42

Sex Ratio in A. nixo-martini on P. bidens eggs at 28°C and 75% relative humidity.

	Period between emergence of females and their oviposition		No. of parasitised eggs in egg masses	No. of progeny	
				Males	Females
	Day	hours			
Replicate	3	2	14	2	12
	4	3	9	2	7
	4	4	7	1	6
	4	4.5	7	1	6
	4	5	7	0	7
	8	3	16	4	12
Total and Average	4.5	3.5	10	1.6	8.3
Replicate	3	4	10	2	8
	3	5	8	1	7
	3	5.5	14	2	12
	3	6.5	13	1	12
	3	7.5	17	1	16
	8	2	19	6	13
Total and Average	3.8	5.08	13.5	2.16	11.3
Replicate	3	5	6	1	5
	3	5.5	14	5	9
	3	6.5	14	2	12
	4	2	15	3	12
Total and Average	3.2	4.7	12.25	2.75	10.25

The results of this experiment are shown in Table 42 and indicate that the sex ratio of males to females is 1 : 5.19; 1 : 5.24 and 1 : 3.72 respectively in three individual females. It also indicates that female No. 1 produced only female progeny in one batch and that the sex ratio varies in different egg masses and with the age of the female.

All attempts to cross this Asolcus with the other species of telenomids studied were unsuccessful. Both sexes always emerged from all egg masses of E. integriceps, P. bidens and P. lituratus which were placed in the field. In all parasitised host eggs collected in the field there was a tendency to higher female progeny.

Host Specificity:

Asolcus nixo-martini is a polyphagous egg parasite of Pentatomoidea. It parasitised and emerged from the eggs of all shieldbugs that were studied. It behaved similarly to A. silwoodensis when the eggs of Ladybirds, or Pieris were supplied to it.

Distribution:

Asolcus nixo-martini were collected in Silwood Park and Cricket Hill, Yateley. Thus, so far, it is known only from central parts of southern England.

Asolcus silwoodensis sp.n.

A) Adult: (see page 238)

B) Morphology of the Immature Stages.

Egg (fig. 69):

Oval and transparent with a long pedicel, its size varying between 0.084 mm to 0.16 mm in length, and from 0.045 to 0.086 mm in width.

First Instar Larva (fig. 69):

It is teleaform and almost transparent. The one-day old larva is about 0.23 mm in length and 0.096 mm in width. At this stage the head and abdomen are defined, whereas the thorax is not. It has a pair of curved, needle-shaped mandibles under which the mouth parts are distinct. The abdomen is long, bearing a long appendage, between which and the abdomen arises a short spinous process. A girdle of about 33 setae surrounds the anterior part of the abdomen.

Second Instar Larva

This larva is sacciform and different from the previous instar. Its size is about 0.73 mm in length and 0.46 in width; it becomes grayish at the end of this instar.

Third Instar Larva (fig. 66):

The third instar larva is hymenopteriform, grayish and opaque. Its length is about 0.97 to 1.05 mm and its width 0.45 to 0.55 mm, when it is fully grown. The head is followed by thirteen visible segments. The larva occupies almost the whole space within the host egg at the end of the third instar. The mandibles are rather short, curved, with a sharp needle-shaped tooth.

Pupa (fig. 70):

The newly emerged pupa is white and gradually changes to gray, then finally to black by the end of the pupal period. Its size is about 0.98 to 1.03 mm in length and 0.48 to 0.52 mm in width. The orange colour of the compound eyes appears in the early days of this stage.

C) Reproductive Organs.

a) Female:

The morphological characters of the female reproductive organs are shown in fig. 69 . They are composed of a pair of ovaries, each having seven polytrophic ovarioles. The common oviduct, spermatheca and the rest of the internal genitalia are similar to those in the previously described species.

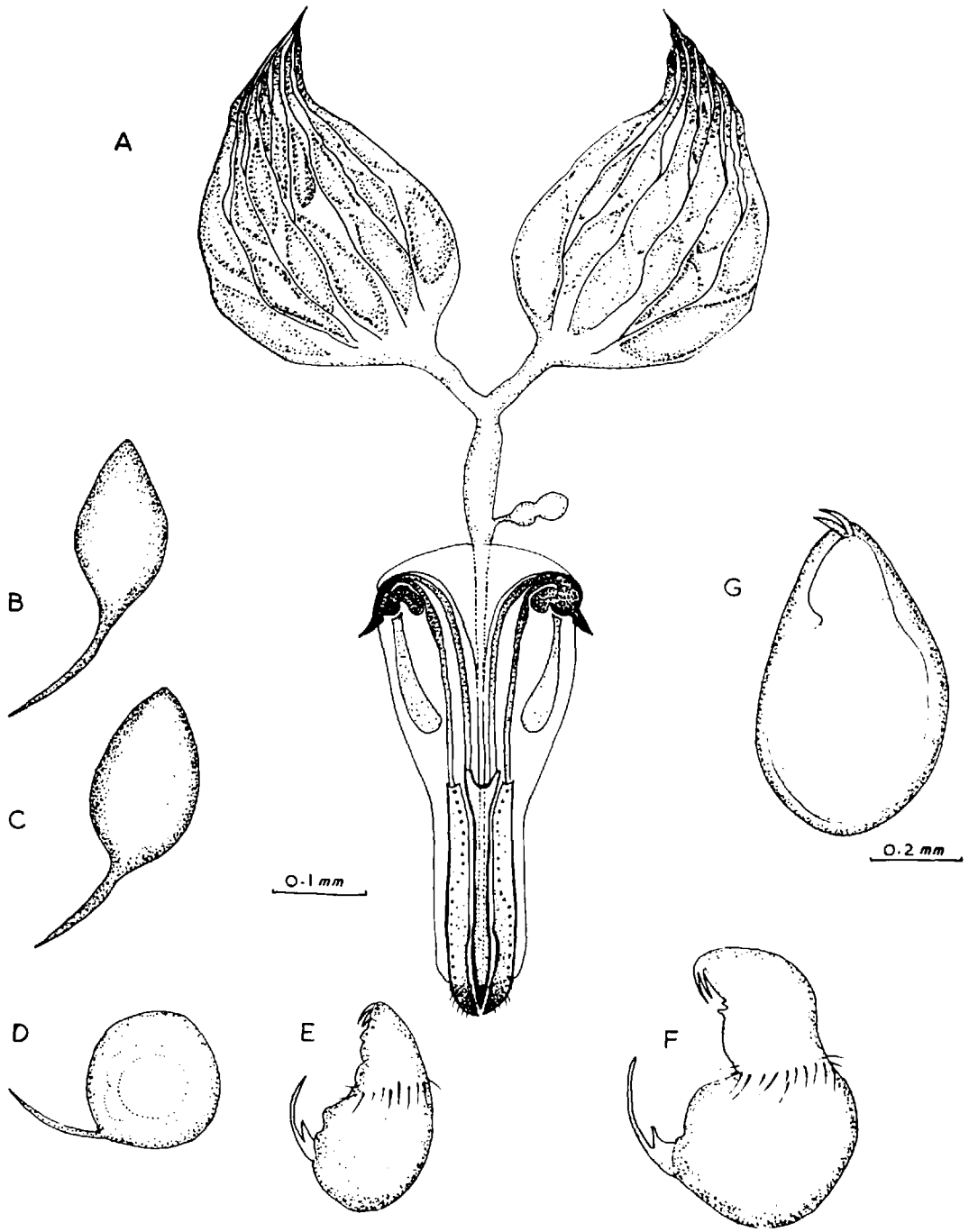


Fig · 69 · Asolcus silwoodensis sp.n. · : A , female reproductive organs ; B , C , eggs ; D , embryonic development in egg ; E , F , first instar larvae ; G , second instar larva before emergence ·

b) Male (fig. 70):

The reproductive organs are composed of a pair of ovoid testes with short vasa deferentia which unite and enlarge to form the common ejaculatory duct. Each testis is enclosed in a double membranous sac. A pair of long tubular accessary glands open into the vasa deferentia before they unite.

The male genitalia are shown in fig. 51. The description is similar to that of the A. waloffae and A. davatchii but they differ from them in size, shape and in the degree of chitinisation.

D) Mating:

Similar to that in the previously described species. In the field mating occurred during June, July, August and September in 1964, 1965 and 1966. The males normally emerge two to five days before the females. In each batch usually the first male possessed and patrolled the egg mass, and behaved similarly to the previously described species, mating with the females just after their emergence. At Yateley copulation was commonly observed on egg masses of P. lituratus on gorse particularly in the morning of warm and sunny days of July. The agressive behaviour of the possessor male, which drove away the other emerging males from the same egg mass, was

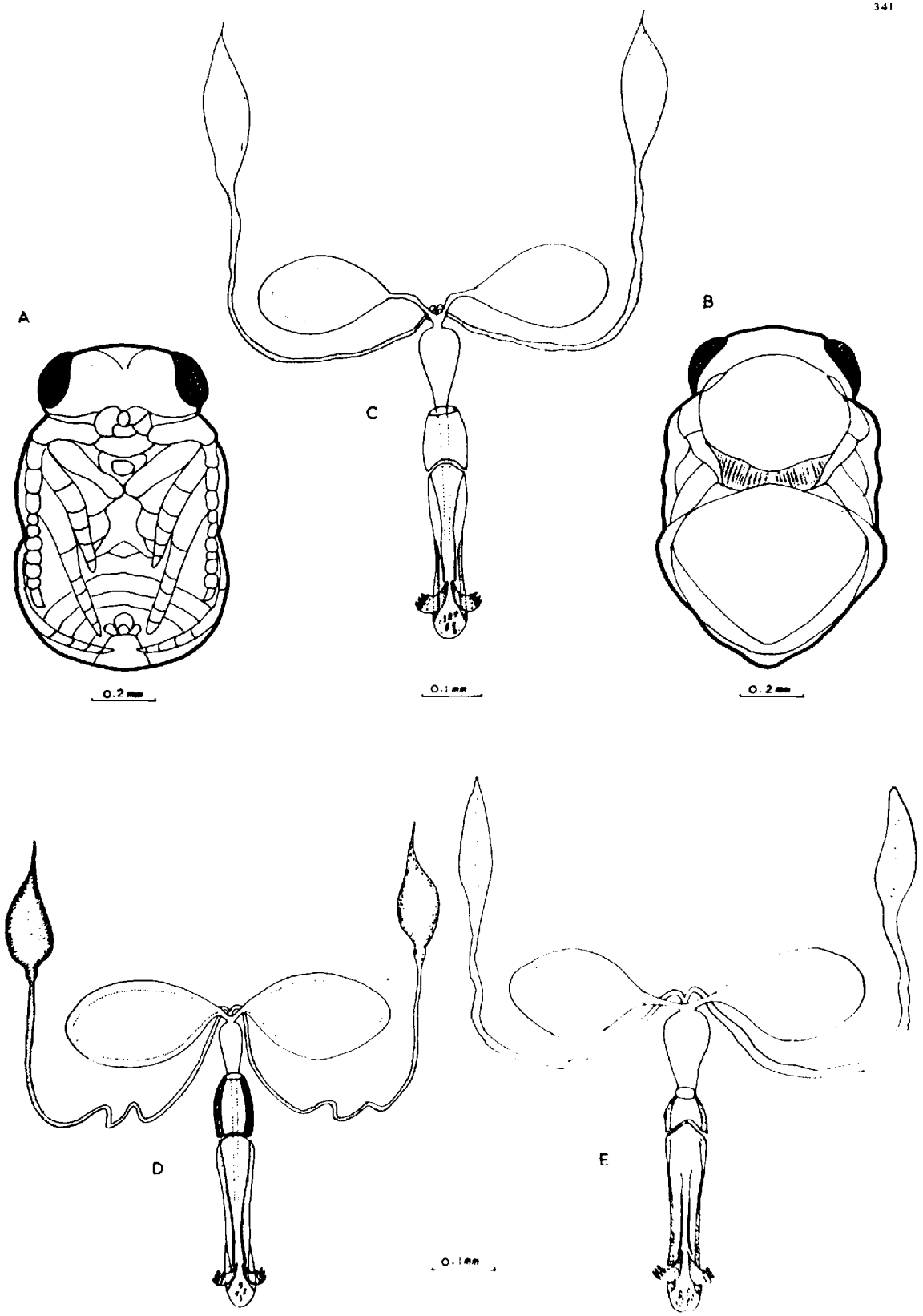


Fig. 70. A, B, **ventral and dorsal views of pupae of** Asolcus silwoodensis sp. n.; C, D, E, **male reproductive organs of:** C, A. silwoodensis sp. n., D, A. grandis Th. (Delucchi) E, A. nixo-martini sp. n.

also frequently observed. Usually the possessor male was found to fertilise all the females which emerged from a batch of 14 to 21 eggs of P. lituratus.

In the laboratory, all attempts to cross this species with A. nixo-martini, A. semistriatus Ns (Delucchi), A. grandis Thom. (Delucchi) were unsuccessful. A number of males of the present species kept together, and also with males of the above species and that of A. davatchii were found to behave as females, i.e. some allowed males to mount them, to drum their antennae or even to stroke their penis on the ventral part of the last abdominal segments.

E) Oviposition:

The oviposition behaviour in A. silwoodensis was similar to that of A. waloffae except in the following points:

1) During oviposition the wings were mostly closed in this species and they usually touched the surfaces of the host eggs.

2) There was a smaller number of the rotating movements in examining the host eggs than in the above species.

The order in which the host eggs were selected was also irregular in this species; diagram 71, shows the irregularity of selection shown by two females. In each batch one of the eggs was parasitised three times by the same

female, but only one parasite emerged from one (B) and none from the other (A). The length of time the parasite took to the host eggs i.e. the egg site of oviposition, the time spent in drilling and ovipositing, marking around the oviposition hole, the length of the resting period and the daily capacity for oviposition were similar to those of A. nixo-martini.

F) Development:

The duration of the developmental period of each stage is shown in Table 43. The parasites were bred on the eggs of A. acuminata, E. integriceps, P. lituratus and P. bidens at 20°C and at 28°C, at 75% relative humidity.

Table 43.

Immature stages	Duration of stage in days			
	20°C		28°C	
	male	female	male	female
Egg	2.0	2.0	1	1
1st instar	3.0	3.5	1.5	2
2nd instar	1.5	2	1	1
3rd instar	3.0	3.5	1.5	2
Pupa	8.5	11	5	6
Total	18	22	10	12

Development period of immature stages are similar, but somewhat shorter than in A. waloffae.

G) The Emergence of the Adult Parasites:

The manner of emergence of the adults from host eggs is similar to that described in A. davatchii, but the time taken to emerge is shorter.

The parasite emerged more rapidly from the eggs of N. pusilla, A. acuminata, E. integriceps, P. prasina and P. lituratus than from the eggs of P. bidens, probably because the operculum is thickest in the last species. A. silwoodensis also developed in eggs of Coreus marginatus (L.) but the adults failed to emerge.

H) Biological Characteristics of Asolcus silwoodensis sp.n.

Life history

1. Occurrence in the Field:

The overwintered female appears in the field at the time of laying of the first Piezodorus lituratus eggs. The earliest dates on which the parasite was captured in the field at Silwood were 11. 5. 64, 22. 5. 65 and 15. 5. 66. One female was also collected on 27. 5. 66 at Cricket Hill in Yateley (Hants.). The latest dates of collection for this parasite were 12. 8. 65 at Yateley, 14. 8. 65 in the New Forest and 28. 8. 65 at Badger's Mount, Kent.

In the field the males were rare. One specimen was caught on 12. 8. 65 at Yateley and two specimens were taken from gorse on 14. 8. 65 at Queen's Bower, New Forest, (Hants).

During the warm sunny days in late June and throughout July and early August the females of this Asolcus were observed searching for their hosts on gorse. They feed on the same food as A. waloffae.

2. Number of Generations:

At the beginning of the period of oviposition of P. lituratus in 1964, 1965 and 1966 large numbers of egg masses of E. integriceps, P. bidens, A. acuminata and of P. lituratus were placed in the field on gorse and broom. After two weeks the egg masses were collected and transferred to the rearing cages in the field, within the same habitat. After the emergence of the first generation of parasites the females were fed for three to four days on honey dew and were provided with host eggs, which were stored in the laboratory at low temperatures. The later generations were similarly treated. As a check, several egg masses of different shieldbugs parasitised by A. silwoodensis in the laboratory were also transferred to the rearing cages in the field on the first day of development of each generation. This was done to supplement the observations on the development of these parasites.

In this way three successive generations were found to occur in 1964 and 1966 and four in 1965. Diagram (fig. 72) illustrates the life cycle of A. silwoodensis in three seasons.

In the rearing cages the parasites were fed on honey dew. In the summer of 1964 and 1965 ten cages were kept, each containing about 100 parasites of each generation. They were placed both on the top of broom, about 1.5 m from the ground, and also under grass near the base of the broom and gorse bushes. The males of all generations in both series of cages died by the middle of December.

The females of all generations which did not oviposit aestivated and later hibernated within the breeding cages. Between 12 and 15per cent of these overwintered females survived to May in 1965 and 1966. Practically all of them belonged to the third generation. The females of the second, and even of the first generation, also overwintered and survived to the next season, but the percentages of the survivors were even smaller than those of the third generation.

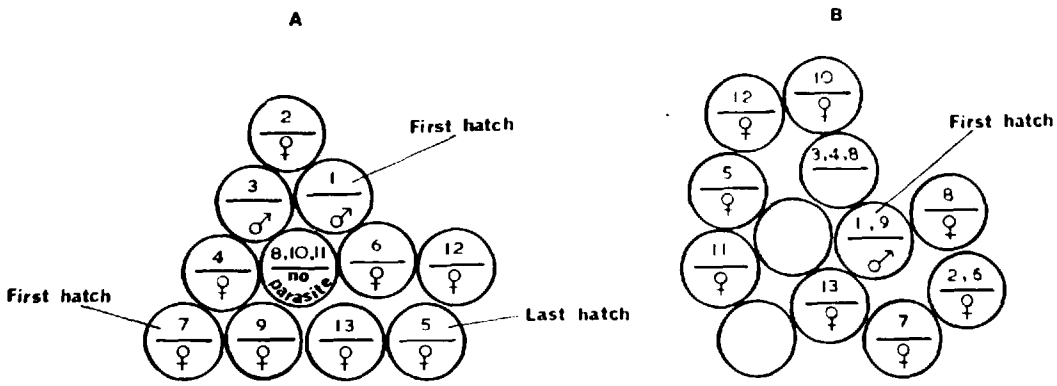


Fig.71. The order in which Hosts were selected during Oviposition and the Sex Ratio of Asolcus silwoodensis sp.n. on Eggs of Picromerus bidens (L.)

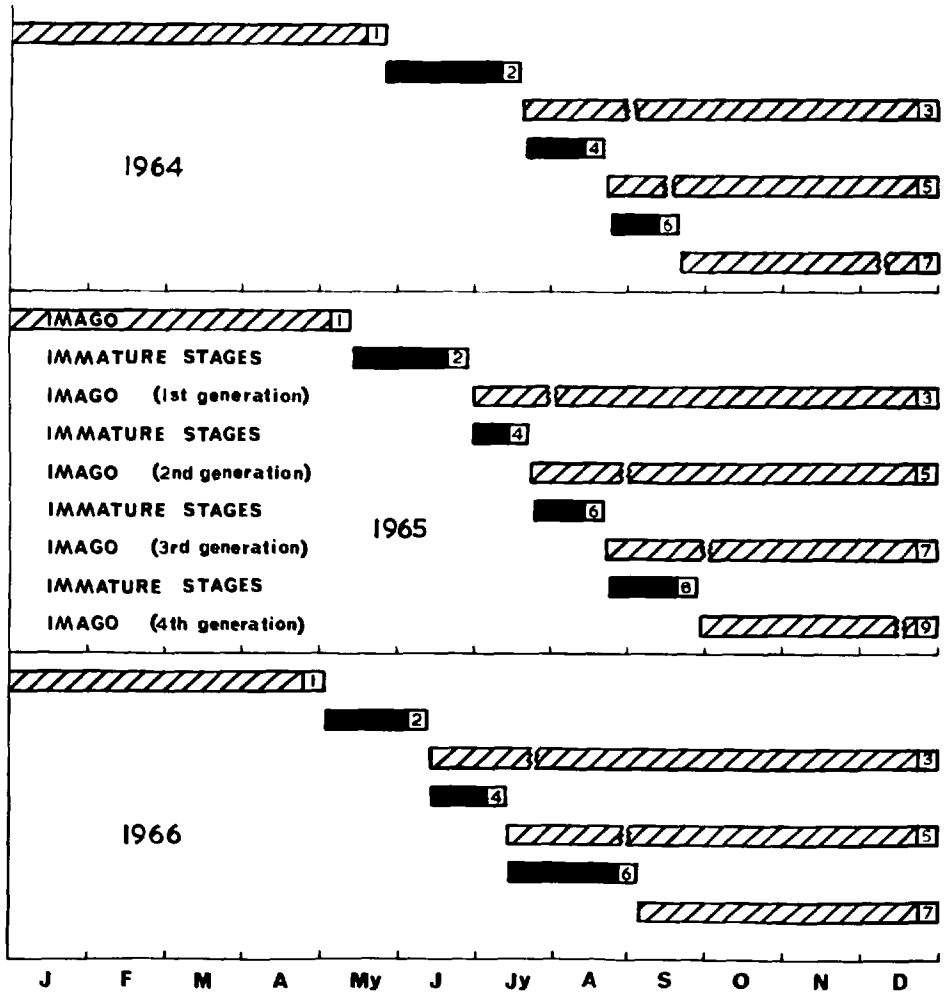


Fig.72. Life history of Asolcus silwoodensis sp.n. in three seasons

1. Period of hibernation of females
2. Black blocks 2,4,6 and 8 depict the 1st, 2nd, 3rd and 4th generations
3. Stencilled blocks 3,5,7 and 9 depict the adult periods of these generations

3. Effect of the host and food on the Longevity and Fecundity of Asolcus silwoodensis sp.n.

a) Field Experiments.

Experiment No. 1:

This experiment was carried out to study the fecundity and longevity of A. silwoodensis upon the eggs of Picromerus bidens. The eggs were about three weeks old and kept at 2 - 3°C before being supplied to the parsites. The females were provided with honey dew throughout their lives. These females were previously bred in the field on P. bidens eggs in July. They were kept within the breeding cages about ten days before being used.

The experiment started on 13. 8. 64 using design No. 1 breeding cages described earlier (see page 204). The batches of host eggs were fixed on strips of cardboard before being introduced into the cages; the parasites were then released within these cages. The females were observed parasitising their host eggs mostly during the warm hours of the morning in the early days at the beginning of the experiment. Their activities, however, decreased to a noticeable degree after about ten days, and they were not observed to parasitise the host eggs later, but were usually seen under the strips of

eggs or leaves of broom within the cages. All females, however, were dead by mid-September.

The parasitised eggs hatched in the early days of September, mostly in the morning. The cages were taken to the laboratory and were checked at low temperature. The results are shown in Table44.

Table 44.

Fecundity of A. silwoodensis sp.n. breeding on P. bidens in the field during August 1964. Food honey dew; host eggs three weeks old kept at 2 - 3°C

No. of replicate	No. of eggs supplied to the parasites		No. of eggs parasitised				Total	% Parasitism
			Parasites hatched		Parasites not hatched			
	batch	eggs	male	female	male	female		
1	4	96	1	63	12	0	76	79.2
2	3	99	4	62	4	5	75	75.8
3	4	95	5	49	6	12	72	75.8
4	5	98	6	40	7	12	65	66.3
5	4	92	2	20	0	0	22	23.9
6	3	96	2	32	12	0	46	47.9
7	4	90	3	63	5	4	75	83.3
8	5	98	6	23	1	5	35	35.7
9	4	93	2	36	7	10	55	59.1
10	3	97	3	51	4	2	60	61.9
Total and Average	3.9	95.4	3.4	43.9	5.8	5	58.1	60.9

Experiment No. 2:

This experiment was carried out to study the longevity and fecundity of A. silwoodensis in the field. In each replicate one female parasite was used. These parasites were taken from the stored cages in the field which were previously bred on E. integriceps eggs in July of the previous season and had overwintered within their breeding cages. They were fed on honey dew throughout their lives. These females were supplied with host eggs of about three weeks old and which had been kept at 2 - 3°C.

The experiment started on 13. 5. 65 using design No. 1 cages as in the other experiment. The batches of host eggs were fixed on strips of cardboard before being introduced into the cages. The females parasitised most of the host eggs during warm and sunny periods of the early days of the experiment and all died by the end of June. Those eggs which were parasitised hatched during the last week of June; these parasites were checked and recorded in the laboratory at low temperature as described before. The results are shown in Table 45.

Table 45.

Fecundity of A. silwoodensis sp.n. breeding on E. integriceps eggs in the field during May and June, 1965. Food honey dew; host eggs three weeks old kept at 2 - 3°C

No. of replicates	No. of eggs supplied to the parasites		No. of eggs parasitised					
			Parasites hatched		Parasites not hatched		Total	% Parasitism
	batch	eggs	male	female	male	female		
1	6	72	2	13	0	2	17	23.6
2	7	84	7	46	0	4	57	67.9
3	6	74	5	33	0	3	41	55.4
4	6	70	6	32	1	1	40	57.1
5	6	72	7	45	0	4	56	77.8
6	6	76	8	48	1	0	57	75.0
7	7	78	7	42	2	9	60	76.9
8	6	74	5	25	0	2	32	43.2
Total and Average	6.25	75	5.9	35.5	0.5	3.1	45	60.0

Analysis of Field Data:

The results of the first experiment (Table 44) indicate that the females parasitised 60.9 per cent of the eggs offered to them and that the sex ratio of male to female was approximately 1 : 5. It also showed that the developmental stage of the A. silwoodensis on the eggs of P. bidens was about

20 days in August 1964. The females lived for at the most a month after being introduced to their breeding cages.

The results of the second experiment (Table 45) indicated that the females parasitised 59.6per cent of the eggs offered to them and that the sex ratio was about 1 : 6. The development of the immature stages lasted about 40 days in May and June 1965. The females lived at most 45 days after they were introduced into the breeding cages.

Since the eggs of E. integriceps and P. bidens were parasitised by A. silwoodensis in the field, the results of the above experiments may show an approximate percentage of parasitism and also the sex ratio in different months of the two seasons. They also show the difference in rates of development in different climatic conditions in August, 1964 and in May and June 1965. The length of the developmental period of this parasite was found to be almost the same on the eggs of P. bidens, E. integriceps, P. lituratus and A. acuminata in the field and in the laboratory. Thus a comparison of the above data in these two experiments show that this period was about 20 days in 1964 and 40 days in 1965. This is mainly due to the differences in temperature in the two years and possibly to other unknown climatic conditions. The average monthly temperatures, radiation, relative humidity and rainfall in 1964 and 1965 are given in Table 1, page 56.

b) Laboratory Experiments.

Experiment No. 1:

This experiment was done to investigate the fecundity and longevity of A. silwoodensis laying upon two week old eggs of P. bidens previously stored at 2 - 3°C. The parasites were given water only throughout their lives. Breeding cages consisted of round plastic boxes of No. 1 design. In each replicate a pair of parasites bred at 20°C and fed on water was used. The host eggs were supplied to parasites in the first three days of their oviposition period. The experiment was carried out at 20°C and 75% relative humidity.

The results are shown in Table 46, and indicate that the females lived slightly longer than the males and that they parasitised 29.6 Per cent of the host eggs offered to them. The sex ratio was approximately one male to three females. Finally, the data show that A. silwoodensis is able to copulate, mature and oviposit when no food, but water is provided; however in these conditions the percentage of parasitism and longevity of the parasites had significantly decreased.

Experiment No. 2:

This experiment was the same as the first one, but pollen was provided for the parasites throughout their lives.

Table 46.

Fecundity and Longevity of *Asolcus silwoodensis* sp.n. breeding on *P. bidens* eggs at 20°C. Diet water only; hosts two weeks old previously kept at 2 - 3°C

Pairs number (replicates)	Longevity in days		No. of eggs supplied to parasites	No. of eggs parasitised					
				Parasites hatched		Parasites not hatched		Total	% Parasitism
	Male	Female		Male	Female	Male	Female		
1	4	6	102	2	26	1	0	29	28.4
2	2	3	105	21	0	2	0	23	21.9
3	12	2	103	6	32	0	0	38	36.9
4	3	3	101	5	18	0	4	27	26.7
5	3	4	104	3	21	2	6	32	30.8
6	5	7	100	4	16	1	2	23	23.0
7	3	4	103	7	26	0	1	34	33.0
8	4	4	103	2	12	1	3	18	17.5
9	6	5	101	6	25	0	1	32	31.7
10	6	3	105	2	19	0	4	25	23.8
11	5	4	107	3	22	0	1	26	24.3
12	4	8	105	6	18	1	3	28	26.7
13	3	6	104	8	26	0	4	38	36.5
14	4	10	102	18	42	3	2	65	63.7
15	14	6	102	3	18	1	6	28	27.5
16	5	7	106	5	12	0	3	20	18.9
17	9	8	101	3	23	0	0	26	25.7
18	7	7	103	42	0	1	0	43	41.7
19	3	9	102	2	18	1	4	25	24.5
Total and Average	5.4	5.6	103.1	7.8	19.7	0.7	2.3	30.5	29.6

Table 47.

Fecundity and Longevity of *Asolcus silwoodensis* sp.n. breeding n *P. bidens* eggs at 20°C. Diet pollen and water; hosts two weeks old previously kept at 2 - 3°C

Pairs number (replicates)	Longevity in days		No. of eggs supplied to parasites	No. of eggs parasitised					
				Parasites hatched		Parasites not hatched		Total	%
	Male	Female		Male	female	Male	Female		Parasitism
1	5	8	103	3	26	0	0	29	28.2
2	4	7	98	5	30	0	1	36	36.7
3	6	9	104	5	19	0	2	26	25.0
4	3	10	101	2	11	0	2	15	14.6
5	9	7	106	2	37	0	0	39	36.8
6	6	6	102	2	20	0	0	22	21.6
7	4	8	99	3	19	0	2	24	24.2
8	10	7	90	1	4	0	0	5	5.6
9	11	12	103	3	16	1	6	26	25.2
10	5	8	105	4	21	0	1	26	24.8
11	12	7	101	3	34	0	0	37	36.6
12	8	9	98	3	27	0	0	30	30.6
13	10	8	103	3	15	0	1	19	18.4
14	4	6	104	3	14	0	0	17	16.3
15	12	9	102	1	17	0	0	18	17.6
16	10	8	106	2	22	0	0	24	22.6
17	12	10	98	3	22	1	5	31	31.6
18	11	9	99	3	17	0	3	23	23.2
19	9	7	101	2	18	0	2	22	21.8
20	7	13	96	4	21	0	0	25	26.0
Total and Average	7.9	8.4	101	2.9	20.5	0.1	1.3	24.7	24.45

The results are shown in Table 47 , and indicate that both sexes lived longer but that the percentage of parasitism has unexpectedly decreased to 24.4 per female. The sex ratio also changed to 1 : 7. Therefore it seems that this parasite could utilise pollen and water to increase its longevity but that the percentage of parasitism (i.e. fecundity of the females) still remained low at 20°C.

Experiment No. 3:

This experiment was carried out at 28°C using the eggs of E. integriceps as hosts. A pair of one day old A. silwoodensis bred at 25°C was used. Throughout their lives the parasites were given water only; the host eggs were supplied in the first three days of the experiment. Breeding took place at 20°C and 75% relative humidity.

The results of this experiment are shown in Table 48 , and indicate that the females lived longer than the males, and that they parasitised 26.3 per cent of the host eggs offered to them. The sex ratio was approximately 1 male to 4 females. Thus fecundity again was unaffected.

Experiment No. 4:

This experiment was similar to experiment No.3 except that the diet was changed and the parasites were fed on honey and 5% sucrose solution. The results are shown in Table 49.

Table 48.

Fecundity and Longevity of *Asolcus silwoodensis* sp.n. breeding on *Eurygaster integriceps* eggs at 28°C. Diet water only; hosts one week old previously kept at 2 - 3°C

Pairs number (replicates)	Longevity in days		No. of eggs supplied to parasites	No. of eggs parasitised				Total	% Parasitism
				Parasites hatched		Parasites not hatched			
	Male	Female		Male	Female	Male	Female		
1	3	5	102	2	24	0	1	27	26.5
2	3	5	98	1	9	0	2	12	12.2
3	4	4	98	2	25	0	0	27	27.6
4	3	6	104	6	15	0	9	30	28.8
5	4	6	100	6	32	0	0	38	38.0
6	4	5	98	7	27	0	0	34	34.7
7	3	3	92	2	19	0	1	22	23.9
8	4	5	101	5	18	0	1	24	23.8
9	3	6	99	3	25	0	0	28	28.3
10	4	5	94	3	26	0	0	29	30.6
11	4	4	102	6	18	0	1	25	24.5
12	4	4	98	2	6	0	0	8	8.2
13	3	6	103	5	22	1	0	28	27.2
14	4	5	101	3	13	0	6	22	21.8
15	4	6	98	1	18	0	11	30	30.6
16	4	4	99	17	11	0	0	28	28.3
17	5	5	102	24	2	0	0	26	25.5
18	4	6	98	0	16	0	8	24	24.5
19	4	5	103	6	27	0	0	33	32.0
20	4	5	100	15	10	0	0	25	25.0
Total and Average	3.75	5.0	99.5	5.8	18.15	0.05	2.0	26.0	26.1

and indicate that the females parasitised 63.4 per cent of the host eggs offered to them and that both the males and the females lived much longer than in the previous experiments. The females however lived for a slightly shorter period than the males while the sex ratio of male to females was 1 : 6.

A comparison between experiment No. 3 and No. 4, indicates that diet greatly affects the fecundity and longevity of the parasite.

Experiment No. 5:

This experiment was carried out to study the possibility of inter-breeding between two closely related species of parasites. In each replicate a one day old virgin female of A. silwoodensis sp.n. and that of a male of A. nixo-martini sp.n. bred at 25°C were used. To ensure contact between the sexes the virgin females and the males (both only a few hours after their emergence) were kept for about five hours in a small test tube. The male in each replicate frequently mounted the female and attempted to copulate with her, but no mating was ever observed. Also the females allowed the males to mount them, but they never straightened their antennae against those of the male, and never extended their ovipositor to enable the male to copulate. After this test the female and male of

Table 49.

Fecundity and Longevity of Asolcus silwoodensis sp.n. breeding on Eurygaster integriceps eggs at 28°C.

Diet honey and 5% sucrose solution; host one week old previously kept at 2 - 3°C

Pairs number (replicates)	Longevity in days		No. of eggs supplied to parasites		No. of eggs parasitised					
					Parasites hatched		Parasites not hatched		Total	% Parasitism
	Male	Female	Batch	Eggs	Male	Female	Male	Female		
1	20	22	8	104	9	58	1	3	71	68.3
2	19	18	8	110	10	56	0	5	71	64.5
3	22	13	8	97	14	35	0	2	51	52.6
4	18	15	8	104	5	66	0	2	73	70.2
5	12	16	7	98	8	50	1	3	62	63.3
6	19	18	7	99	10	43	2	6	61	61.6
Total and Average	18.3	17.0	7.7	102	9.3	51.3	0.66	3.5	64.8	63.5

each replicate were introduced into their breeding cages (design No. 1) and were kept together for three days before the host eggs were supplied to the females. The parasites were provided with honey and 5% sucrose solution throughout their lives. Breeding was carried out at 28°C and 75% relative humidity.

The results of this experiment are shown in Table 50, and show that the females produced male progeny only. It can also be seen that the females lived longer than males, that 52.8per cent of the host eggs were parasitised and also indicates that the male progeny was produced parthenogenetically.

Table 50.

Cross-breeding of Female Asolcus silwoodensis sp.n. with Male A. nixo-martini sp.n. on Eurygaster integriceps eggs at 28°C. Diet honey and sucrose solution; hosts one week old previously kept at 2 - 3°C

No. of replicates	Longevity in days		No. of eggs supplied to parasites		No. of eggs parasitised				Total	% Parasitism
					Parasites hatched		Parasites not hatched			
	Male	Female	Batch	Eggs	Male	Female	Male	Female		
1	4	10	8	96	56	0	4	0	60	62.5
2	21	13	8	102	63	0	6	0	69	67.6
3	19	17	8	95	50	0	5	0	55	57.9
4	18	21	8	100	28	0	0	0	28	28.0
5	14	12	7	98	47	0	0	0	47	48.0
Total and Average	15.2	14.6	7.8	98.2	48.8	0.0	3.0	0.0	51.8	52.7

Parthenogenesis:

Similar to Asolcus davatchii and A. waloffae the females of A. silwoodensis were able to lay parthenogenetically the resulting progeny always being male. All attempts to cross the females of the present species with males of two Asolcus species mentioned above and those of A. nixo-martini (see Table 50), A. semistriatus Ns. (Delucchi), A. grandis Thom. (Delucchi) as well as with males of Telenomus truncatus Mayr and T. sokolovi Mayr were unsuccessful; mating was never observed and the resulting progeny was always male.

All the females of A. silwoodensis collected in the field at Silwood Park, Yateley, the New Forest, Kent, and tested in the laboratory produced both sexes. This indicated that in nature the females were usually fertilised. All parasitised egg masses of P. lituratus collected in southern England and hatched in the laboratory resulted in both sexes from every single egg mass, except one batch which resulted in females only. This batch consisted of 14 eggs of P. lituratus collected at Queen's Bower in the New Forest on gorse on 14. 8. 65 from which 14 females emerged on 16. 8. 65 in the laboratort. From all other batches of host eggs of E. integriceps and P. bidens parasitised in the field and hatched in the laboratory, at least one male always emerged from each egg mass; this ensures fertilisation of the females.

It was observed repeatedly that a single male could fertilise all the Asolcus females emerging from a batch of 7, 10, 12, 14, 21 and 28 eggs of the above mentioned Pentatomoidea.

Sex Ratio and Factors Influencing the Sex of the Parasites

The sex ratio of the parasites emerging from the egg masses collected in the field was one male to 5 females. In the laboratory the ratio of males to females varied from 1 : 4 to 1 : 6 under different diet and breeding conditions; in one experiment on which parasites were fed on water only throughout their life this ratio was 1 : 3.

The results of preliminary studies also indicated that:-

1) Virgin females always produce males only and fertilised females produce both sexes with a higher ratio of females.

2) All the progeny were found to be males when the females laid within a few hours after mating.

3) The sex ratio of male to female changed to about 1 : 5 after three days of fertilisation of the females.

4) There was a tendency to produce males in early and in the late oviposition on a single host egg mass, but in

one case the production of a male also occurred in the middle of oviposition.

5) It appeared that the sex ratio of the parasites was affected both by the diet and by the species of the host egg.

6) Females of large size (emerged from eggs of P. bidens or Palomena prasina) were fertilised by males of about half their size (emerged from eggs of Aelia acuminata or Neottiglossa pusilla) or vice versa; in both cases both sexes were produced (fig. 50).

Host Specificity:

Asolcus silwoodensis is a polyphagous egg parasite of Pentatomoidea. It parasitised, developed and emerged, from the egg of all the shieldbugs that were studied. It also parasitised and developed on eggs of Coreus marginatus (Coreidae). In the laboratory A. silwoodensis parasitised the eggs of Dysdercus fasciatus Sign.(Pyrrhocoridae) and "Tiger" moth (Arctia caja L., Arctiidae) but no parasites ever developed in these eggs; although the size, form, colour, and also to some extent, the sculpture of the "Tiger" moth eggs was similar to that of E. integriceps.

A. silwoodensis never parasitised the eggs of Pieris brassicae (Pieridae) and showed a rather peculiar behaviour when she drummed on the eggs of Coccinella septempunctata and those of Adalia bipunctata (Coccinellidae); e.g. the females having touched the eggs of the ladybirds immediately ran away and stroked the clubs of the antennae several times against the surface of the cardboard nearby. Later the parasite remained immobile bending her antennae over her head for about two minutes. This parasite also did not lay in the eggs of Leptopterna ferrugata (Fallén) (Miridae) nor in those of several species of spiders.

No reasons can be suggested why Asolcus failed to parasitise the eggs of the above species and actively avoided those of the coccinellids. It is, however, probable that sensitive chemoreceptors were involved in this behaviour.

Distribution:

Asolcus silwoodensis is a common scelionid in southern England. It was collected in Silwood Park (Berks), Yateley and the New Forest (Hants), Wisley Common (Surrey) and Badger's Mount (Kent). Thus so far, it is known only from southern England.

Telenomus sokolovi Mayr

A) Adult: (see page 261).

B) Morphology of the Immature Stages:

The morphological characters of the egg; first and third instar larvae, as well as pupa, are shown in fig.73. They are similar but somewhat smaller in size from those of T. truncatus; therefore, the detailed description given for the latter species will serve for T. sokolovi.

C) Reproductive Organs.

a) Female Reproductive Organs:

The morphological characters of reproductive organs of a female in the post oviposition period are shown in fig. 73. The pair of ovaries are each composed of seven ovarioles which can be separated at this stage. The ovaries, common oviduct, spermatheca and the external genitalia are similar but smaller in size than those of T. truncatus.

b) Male Reproductive Organs (fig. 73):

They are similar to those of T. truncatus apart from the external genitalia which are different in shape and the degree of chitinisation (fig. 56). The number of teeth on each clasper appeared to be variable; in the majority the claspers were symmetrical each bearing three heavily chitinised teeth on one side, but among the large number of specimens studied, some had four teeth on each clasper or were asymmetrical

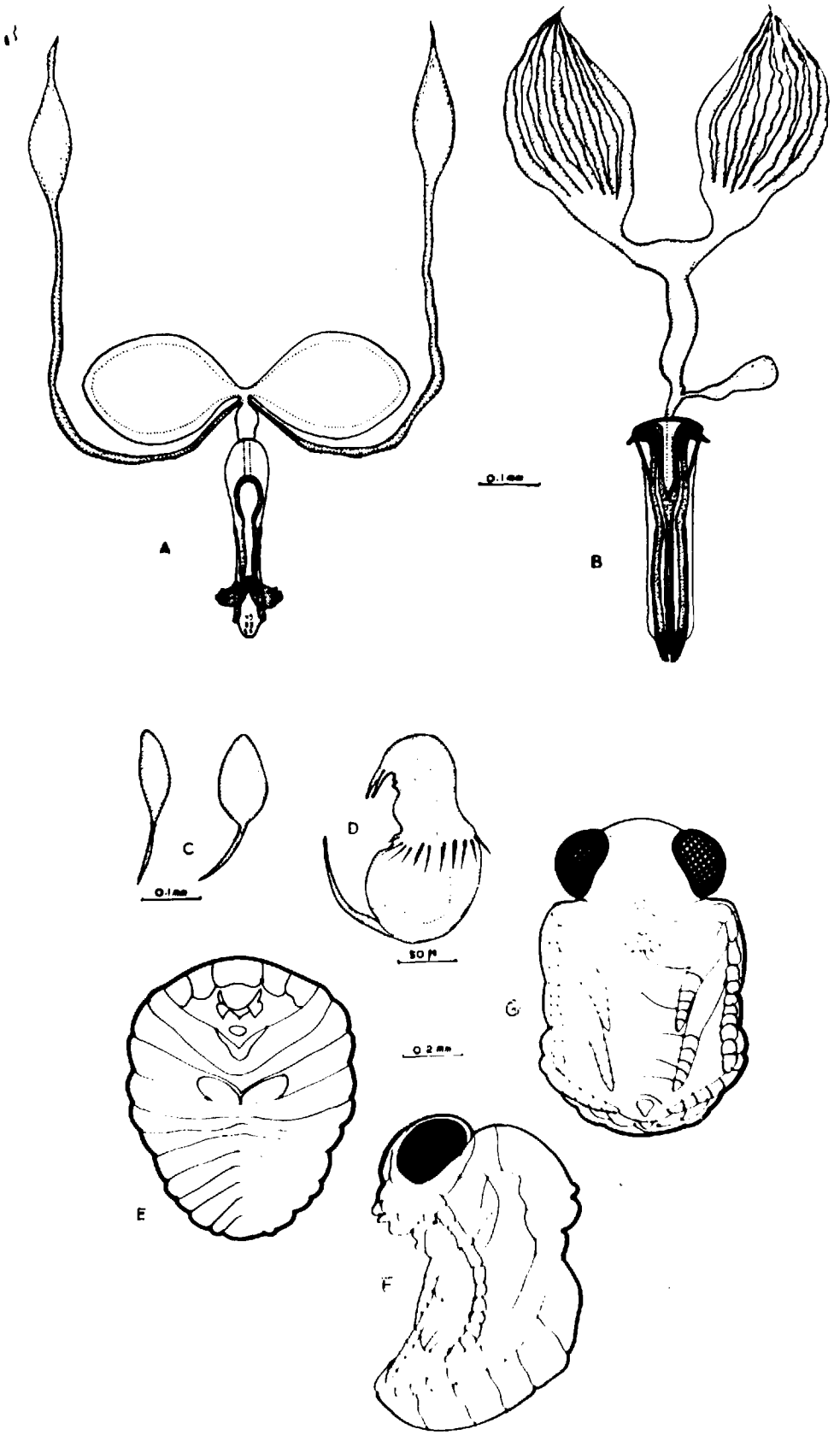


Fig. 93. Telenomus Sokolovi Mayr. — A. male and B. female reproductive organs at post-oviposition period, C. eggs, D. first and E. third instar larvae, F. lateral and G. dorsal views of pupae

having three teeth on one side and four on the other (see fig. 56). The Russian specimens were symmetrical bearing three teeth on each clasper.

D) Mating:

In the field mating occurred towards the end of June, in July, and early August during the warm and particularly sunny days at Yateley in 1965 and 1966. The process of mating was similar to that in T. truncatus and that of Asolcus spp. The females behaved similarly to the males as was described in the previous species. The duration of mating was similar to T. truncatus (between 30 - 75 seconds) but longer than that of Asolcus spp. The males were distinctly less agressive while they were patrolling the egg mass for fertilising the females than T. truncatus and all the Asolcus species.

E) Oviposition:

The general process of oviposition behaviour in T. sokolovi was similar to that of Asolcus spp. and T. truncatus apart from the following points:

1) During the oviposition the wings were mostly open or rarely half open (see Table 51). Their wings, however, did not normally touch the surface of the egg host.

2) Similar to T. truncatus marking of the host egg was mostly made on the top of the egg.

3) The agressive behaviour of a female, in driving the other females away from an egg mass in order to parasitise all the eggs was noticeably less often exhibited than that of T. truncatus and Asolcus spp, In the laboratory it was observed that two females were parasitising one batch of 10, 12 or 14 eggs together. It was also observed that two females parasitised even a single egg at the same time while being very close to one another during this process.

4) Similar to T. truncatus, the present species preferred to lay on large host eggs (i.e. eggs of E. integriceps) than those of small size (i.e. eggs of A. acuminata or N. pusilla).

5) The side of the oviposition was mostly near the bottom of the egg (see Table 51).

The order in which the host eggs were selected was also irregular in T. sokolovi; diagram 77 illustrates the irregularity of selection shown by a female. The details of successful oviposition for one female during one day are given in Table 51.

F) Development:

The developmental periods of T. sokolovi were slightly shorter than those of T. truncatus; i.e. the total duration of male development from egg to adult was 15 days and that of the female was 16 at 25°C and 75% relative humidity. Thus the detailed description given for T. truncatus at various

temperatures presents a close approximation of the developmental periods of the different stages of T. sokolovi.

Table 51. Time taken in oviposition behaviour by one T. sokolovi on P. lituratus eggs in one day.

No. of parasitised egg	Time required for a successful oviposition of each egg						
	Examination		Drilling and oviposition		Marking	Site of oviposition	Position of the wings
	Minute	Second	Minute	Second	Second		
1	0	15	3	40	no	bottom	half open
2	0	45	4	40	no	"	"
3	1	10	5	13	15	"	"
4	0	28	4	30	35	"	"
5	0	34	5	33	18	"	open
6	0	44	3	18	22	"	"
7	0	23	2	17	no	"	"
8	0	48	2	16	no	"	"
9	1	10	3	22	26	"	half open
10	0	38	4	33	25	"	"
11	0	17	4	24	21	"	open
12	0	22	3	10	25	"	half open
13	0	56	4	10	28	"	open
14	0	28	3	50	no	lateral	"
15	2	46	2	24	no	"	"
Total and Average	0	46	3	08	15	Bottom 86.7% Lateral 13.3%	half open 46.7% open 54.3%

G) The Emergence of the Adult Parasite:

The process of emergence of T. sokolovi was similar to that in Asolcus spp. and T. truncatus but the diameter of the emergence hole on the operculum was distinctly shorter in the present Telenomus than in the above species. In several cases the parasites even emerged from the emergence holes which were less than half of the diameter of the operculum. T. sokolovi emerged easily from the eggs of phytophagous Pentatomoidea such as P. lituratus and E. integriceps but it practically failed to emerge from the eggs of P. bidens and only 6% were able to bore the emergence hole large enough to emerge successfully from the eggs of this predacious shieldbug.

H) Biological Characteristics of Telenomus sokolovi Mayr

Life History

1. Occurrence in the Field:

The overwintered females appear in the field somewhat later than T. truncatus. Two females were collected on gorse on 3. 6. 65 and one on 27. 5. 66 at Cricket Hill, Yateley. Only one female of T. sokolovi was collected at Silwood Park during a very warm and sunny day at Gunnes's Hill from broom on 28. 6. 65.

2. Number of Generations:

During 1965 and 1966, the number of generations of T. sokolovi was studied at Cricket Hill in Yateley and at

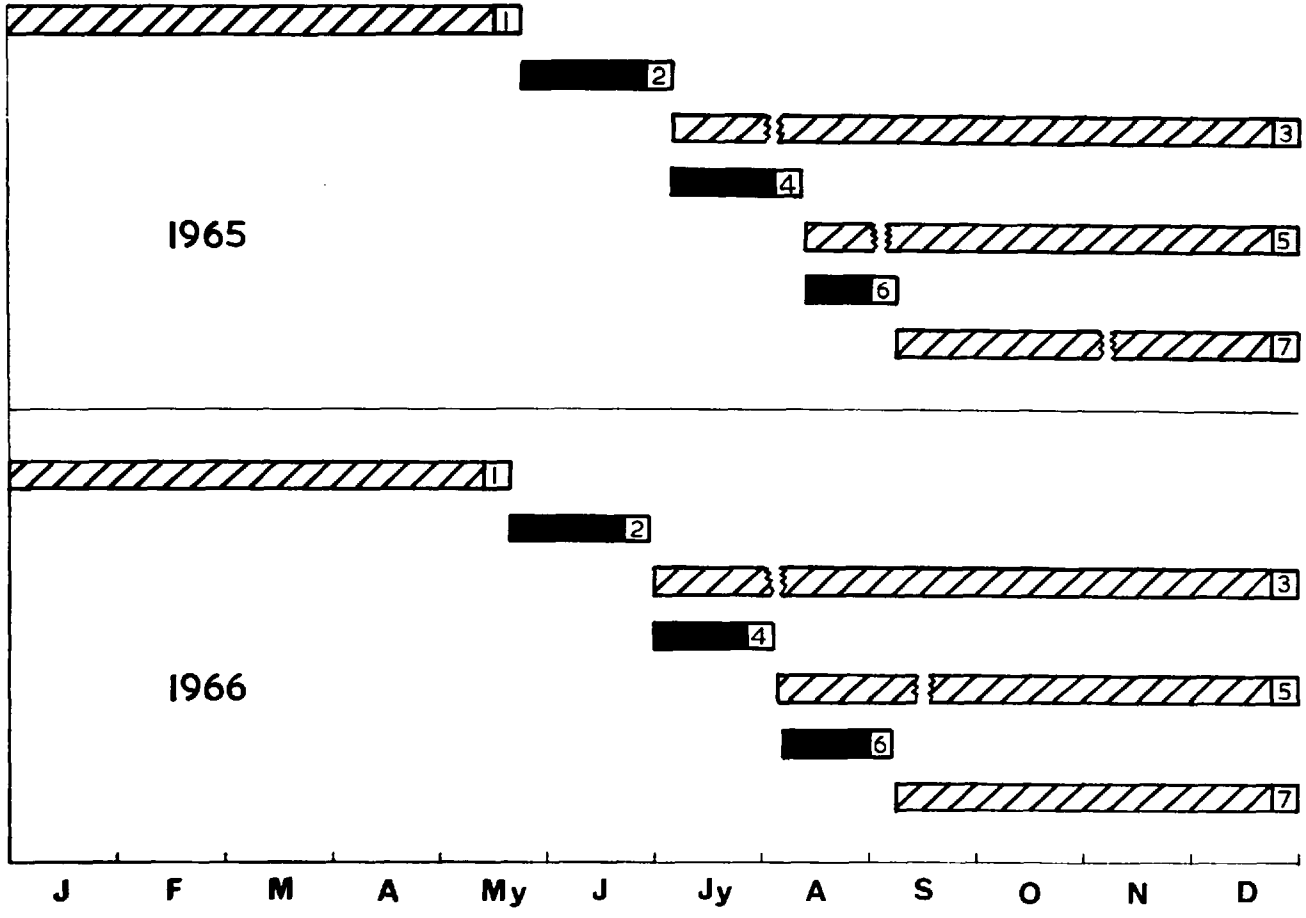


Fig. 74 Life history of Telenomus sokolovi Mayr in two seasons

1. Period of hibernation of females
2. Black blocks 2, 4 and 6 depict the 1st, 2nd and 3rd generations
3. Stencilled blocks 3, 5 and 7 depict the adult periods of these generations

Silwood Park. The method of the investigation was similar to that described for the previous species of parasites. The host eggs were mostly P. lituratus but the egg masses of E. integriceps, A. acuminata and P. bidens were also placed in the field for this study. In this way three successive annual generations were found to occur. Diagram (fig. 74) illustrates the life cycle of Telenomus sokolovi in 1965 and 1966. The males of the first and second generation died during August and September and those of the third generation by the middle of October. The females of the first and those of the second generation died several weeks after their oviposition, but those of the third generation aestivated and hibernated in the breeding cages. These females were fed on honey dew and only 4% survived until the next Spring.

3. Fecundity and Longevity of T. sokolovi upon the five-month old eggs of E. integriceps previously kept at 2 - 3°C

The parasites were reared under similar conditions to those described for T. truncatus. Each breeding cage contained a pair of parasites bred at 25°C. The results of these observations are shown in Table 52 . The diet obviously prolonged their lives as the parasites under the same conditions did not survive more than five days when they were fed on water only. The females lived longer than the males, but similar to T. truncatus their fecundity appeared to be low.

Table 52.

Fecundity and Longevity of Telenomus sokolovi Mayr, bred on five-month old eggs of E. integriceps at 28°C and 75% R.H.

Pairs of parasites (replicates)	Longevity in days		No. of eggs supplied to parasites		No. of eggs parasitised				Total of parasitised eggs	% Parasitism
					Parasites hatched		Parasites not hatched			
	Male	Female	Batch	eggs	Male	Female	Male	Female		
1	24	19	8	98	0	0	0	2	2	2.0
2	22	15	7	86	3	0	0	0	3	3.5
3	20	27	8	102	9	1	0	0	10	9.8
4	25	33	8	96	0	0	1	3	4	4.2
5	23	31	9	108	1	7	1	2	11	10.2
Total and Average	22.8	25	8	98	2.6	1.6	0.4	1.4	6	6.1

Parthenogenesis:

Females of Telenomus sokolovi were able to lay parthenogenetically, the resulting progeny being male. Fertilised females produced both sexes. Several females captured in Yateley in June and tested in the laboratory, produced both sexes which indicated that they were fertilised in nature.

Sex Ratio and Factors Influencing the Sex of the Parasites:

The average ratio of male to female of T. sokolovi on eggs of P. lituratus collected at Yateley was 1 : 4.9 in 1966. This ratio was 1 : 1.5 in the first generation of parasites in 1965, and was 1 : 1.1 on eggs of E. integriceps and 1 : 1.4 on eggs of P. bidens (the eggs of this host were

dissected) at Yateley in 1965.

Host specificity:

Telenomus sokolovi is a polyphagous egg parasite of Pentatomoidea. In Yateley (Hants), Piezodorus lituratus is one of its hosts but it also parasitised the eggs of E. integriceps and P. bidens which were placed in the field at Cricket Hill in Yateley in June and July 1965. In the laboratory T. sokolovi parasitised the eggs of the above shieldbugs as well as the eggs of Palomena prasina and A. acuminata. The parasites failed to emerge from the eggs of P. bidens as only 6♀ were able to bore the emergence hole sufficiently for a successful emergence.

Superparasitism:

In the field and in the laboratory superparasitism rarely occurred but usually one or no parasite emerged, except in one egg of a batch of 14 of P. lituratus which resulted in twin females. This batch of eggs was collected on 22.7.66 at Yateley. The parasites were small being head to tail within the egg: one parasite emerged through the operculum, whereas the other emerged through the chorion near the bottom.

Distribution:

Telenomus sokolovi is a rare British egg parasite of Pentatomoidea. It was usually collected in Yateley (Hants), but one specimen was also caught at Silwood Park.

Telenomus truncatus Mayr

A) Adult: (see page 254).

B) Morphology of the Immature Stages.

Egg (fig. 76):

The newly deposited egg is oval, transparent, with a long pedicel. The egg varies between 0.064 mm - 0.12 mm in length, and between 0.042 mm - 0.063 mm in width; the pedicel is almost as long as the egg.

First Instar Larva:

The first instar larva is teleaform and similar to that of T. sokolovi Mayr (fig. 73). It is pale white and its length soon after emergence is about 0.16 mm and it is 0.08 mm in width. At this stage the head and abdomen are defined, but thorax only feebly visible. At the anterior end of the head there are a pair of curved, sharp, distinct and needle-shaped mandibles, under which are situated the mouth opening and the labium.

The abdomen is rather long and curved, bearing a long appendage at its end, which is curved and directed towards the mouth parts. At the anterior part of the abdomen there is a girdle of about 31 setae; their apices are directed posteriorly.

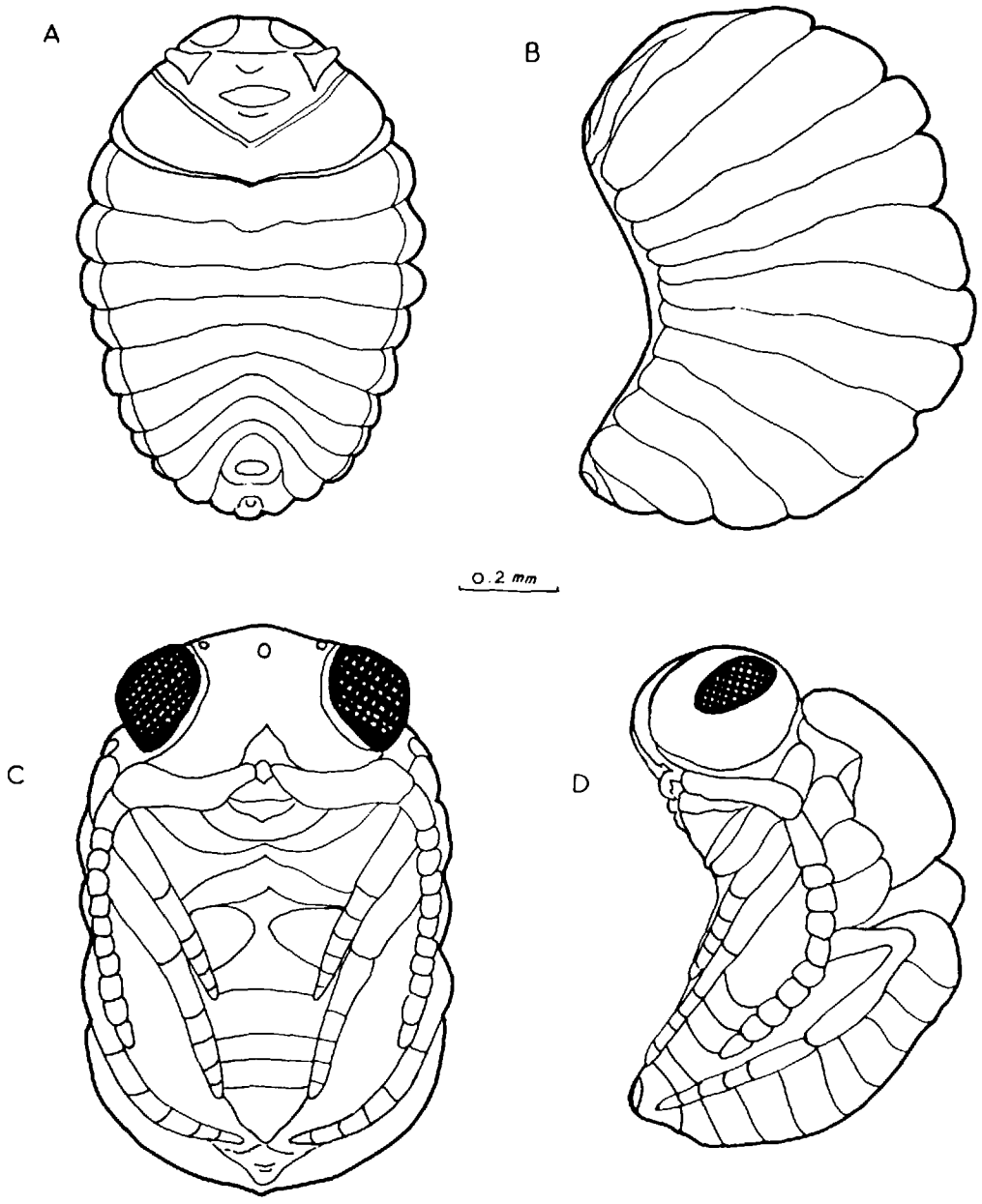


Fig. 75. Telenomus truncatus Mayr: A, ventral; B, lateral views of mature third instar larvae; C, ventral D, lateral views of pupae

Second Instar Larva:

The second instar larva is sacciform and normally hymenopteriform. The second and third instars are similar (fig. 75), but differ in the size of the mandibles and also in the apparent absence of spiracles in the second instar. It is grayish-white, approximately 0.75 mm long and 0.54 mm wide.

Third Instar Larva (fig. 75):

The third or final instar larva is hymenopteriform. The body is cylindrical and grayish; it is about 0.92 mm in length and 0.68 mm in width when it is mature. All the head and the thirteen segments are very distinct and the larva occupies the whole space within the host egg. The mandibles are rather short, each bearing a single curved tooth.

Pupa (fig. 75):

The body is somewhat oval shaped and its colour is at first white but gradually changes to black. It is approximately 1.10 mm in length and 0.54 mm in width. The compound eyes are reddish. The legs, and antennae are on the underside of the abdomen and the wings are placed between them.

C) Reproductive Organs

a) Female Reproductive Organs (fig. 76):

The pair of ovaries are each composed of seven polytrophic ovarioles. The two ovaries lateral oviducts unite together and form the common oviduct which ends in the vagina. A small double-bulbed spermatheca, opens into the vagina near its opening into the ovipositor. The female genitalia are chitinous and narrower than those of the Asolcus spp. They are composed of a pair of long inner valvula plates, each of them being connected to one small and a narrow fulcrum. The other ends of these plates end in sharp and heavily chitinised drilling parts, between which lies the chitinised ovipositor. The end of the ovipositor is acute and screw shaped. The whole ovipositor and the inner plates lie within a rather thin chitinised outer valvula plate. The ovipositor is brownish with about 0.35 mm in length and 0.09 in width.

b) Male Reproductive Organs (fig. 76):

They are composed of a pair of separate, ovoid, testes, which are somewhat transparent. These open into short vasa deferentia which unite and form the common ductus ejaculatorius. A pair of long tubular accessary glands open

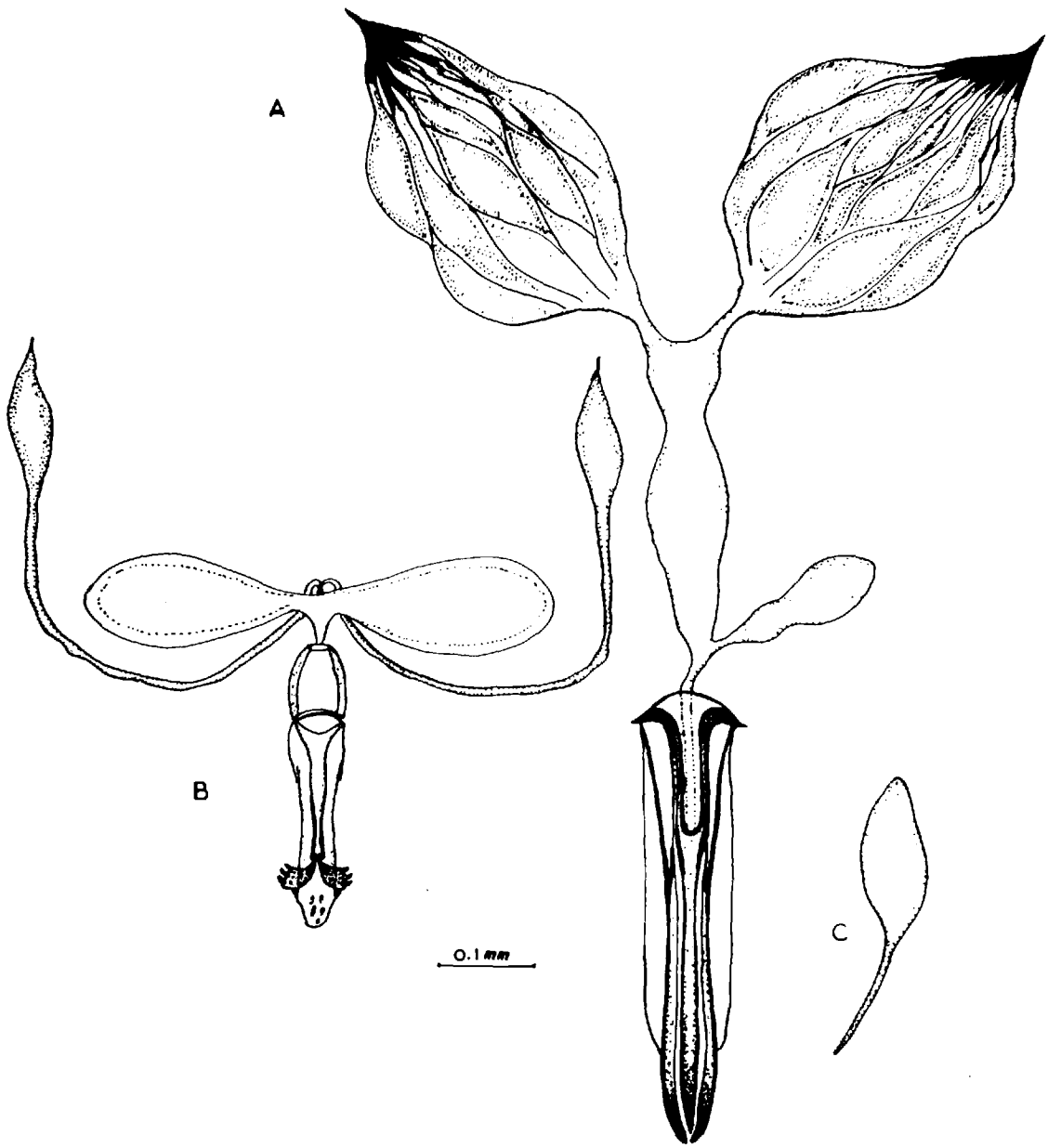


Fig. 76. Telenomus truncatus Mayr: A, female reproductive organs at maturation; B, male reproductive organs; C, egg.

into the vasa deferentia just before they unite.

The external male genitalia (fig. 56) are cylindrical with the ductus ejaculatorius in the middle of the cylinder, which leads to the penis. The genitalia resemble a chitinised tube with different membranous connections anteriorly. This tube consists of an upper and a lower sheath which are joined posteriorly by a membrane. There is a pair of symmetrical claspers, each bearing three stout and heavily chitinised teeth. These claspers are attached to the anterior end of chitinous ribs which are joined to the upper sheath.

D) Mating:

In a broad sense the process of mating in two Telenomus spp. is similar to that in Asolcus spp., therefore the detailed description given for the latter genus will serve for Telenomus. In the field, mating was seen during June, July and August in 1965 and 1966 in the New Forest, Yateley and Silwood Park. The males usually emerged two to five days before the females and normally the first male possessed the egg mass, fertilising the females on their emergence. At Cricket Hill (Hants) mating was very commonly observed on egg masses of P. lituratus on warm and sunny days of July. The

agressive behaviour of the possessor male was also frequently observed. In the laboratory copulation commonly took place at temperatures between 16 and 31 °C. The females respond to the males of their own species only; they behave similarly to the Asolcus spp. in straightening their antennae in recognition of the male and in extending their ovipositors to enable the male to mate with them. All attempts to cross the females of the present species with the males of Telenomus sokolovi Mayr, and those of Asolcus spp. were unsuccessful, the resulting progeny were always males i.e. produced parthenogenetically only. The duration of mating varied from 25 seconds to one minute and 12 seconds and was longer than in the Asolcus spp.

The importance of antennae in mating was investigated experimentally with the following results:-

(+, indicates successful copulation)

		Mating
1)	Both antenna cut off in both sexes	-
2)	One antenna cut off in both sexes	+
3)	Both flagella cut off in the male	-
4)	Both clubs cut off in the female	-
5)	Five apical segments of both flagella cut off in male	-
6)	Three apical segments of both clubs cut off in female	-

	Mating
7) Five apical segments of one flagellum cut off in male	+
8) Three apical segments of one club cut off in female	+

Thus it seems that the sensory organs on the flagellum of male and on the club in the female determine successful mating in T. truncatus. This result was obtained in T. sokolovi and all other Asolcus spp. studied.

E) Oviposition:

In general terms the oviposition behaviour in T. truncatus was similar to that of Asolcus species except for the following points:

1)During the oviposition the wings were always closed and touched the surfaces of the host egg.

2)The marking of the host egg was mostly made on the top of the egg.

The order in which the host eggs were selected was also irregular in T. truncatus; diagram 77 illustrates the irregularity of selection shown by a female. Usually the females laid one egg in each host egg, but superparasitism was also observed in the field and in the laboratory. The details of successful ovipositions in one female during one day are given in Table 53.

Table 53.

Time taken in oviposition behaviour by one T. truncatus on P. lituratus eggs in one day.

No. of parasitised egg	Examination	Drilling and oviposition		Marking	Site of oviposition	Position of the wings
	Second	Minute	Second	Second		
1	58	4	52	25	bottom	closed
2	28	4	12	22	lateral	"
3	38	4	55	36	"	"
4	16	4	05	28	bottom	"
5	16	4	28	16	"	"
6	20	4	16	20	"	"
7	15	4	00	27	"	"
8	24	5	12	10	"	"
9	18	3	43	33	"	"
10	48	4	46	30	"	"
11	33	4	55	28	lateral	"
12	28	3	46	24	bottom	"
13	34	4	38	36	"	"
14	18	6	12	00	"	"
15	21	4	18	00	"	"
16	26	4	32	24	"	"
17	38	5	13	00	"	"
18	48	5	02	00	"	"
Total and Average	29.3	4	61	19.9	bottom 83.3% lateral 16.7%	closed

F) Development:

The developmental periods of each stage were determined by daily dissections of parasitised host eggs kept at 20°, 25° and 28°C.

The parasites were bred on eggs of E. integriceps, A. acuminata, P. lituratus and P. bidens using breeding box (design No. 1); relative humidity was 75%. The results are shown in Table 54. The embryo and larval development are similar to those of Asolcus waloffae.

Table54. Developmental Period of Telenomus truncatus.

Immature stages	Duration of stage in days					
	20°C		25°C		28°C	
	Male	Female	Male	Female	Male	Female
Egg	2.5	2.5	1.5	1.5	1.0	1.0
1st instar	4.0	4.5	2.5	3.0	2.0	2.0
2nd instar	2.0	2.0	1.5	1.5	1.0	1.0
3rd instar	4.0	4.5	2.5	3.0	2.0	2.5
Pupa	12.5	13.5	8.0	8.5	5.0	5.5
Total	25.0	27.0	16.0	17.5	11.0	12.0

G) The Emergence of the Adult Parasite:

The parasites mostly emerge in the morning of warm days. The manner of emergence of the adults is similar to that

in Asolcus spp.; except that in the Telenomus spp., the emergence hole is distinctly smaller (see fig. 60). In some eggs only half of the operculum was chewed by the parasite and emergence was successful. The parasites emerged more rapidly from the eggs of phytophagous Pentatomoidea than from the eggs of the predacious P. bidens.

H) Biological Characteristics of Telenomus truncatus Mayr.

Life history

1. Occurrence in the Field:

The overwintered females appear in the field at the beginning of the period of oviposition of P. lituratus. The earliest dates on which the parasite were captured at Denny Wood in the New Forest was on 15. 5. 65 and on 27. 5. 66 at Cricket Hill in Yateley (Hants). The last parasites were observed in Yateley and Wisley Common in August 1965 and 1966. This parasite was only rarely found at Silwood Park during June, July, August and in early September.

During the warm sunny days in June, July and August the females were commonly observed on gorse at Cricket Hill, walking and flying rapidly on to twigs and around the buds and pods, drumming their antennae and searching for host eggs. They fed on honey dew and nectar of the mixed

Telenomus truncatus Mayr

A

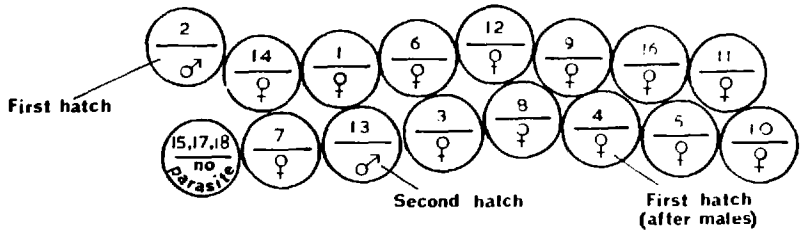
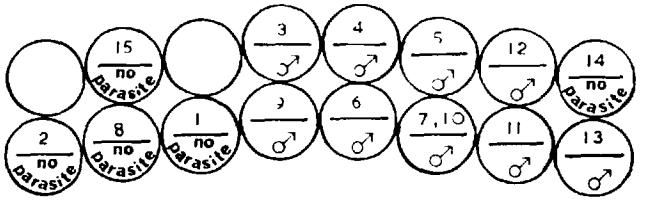


Fig. 77. The order in which Hosts were selected during Oviposition and the Sex Ratio of two British Telenomus spp. on Eggs of Piezodorus lituratus (F.)

B



Telenomus sokolovi Mayr

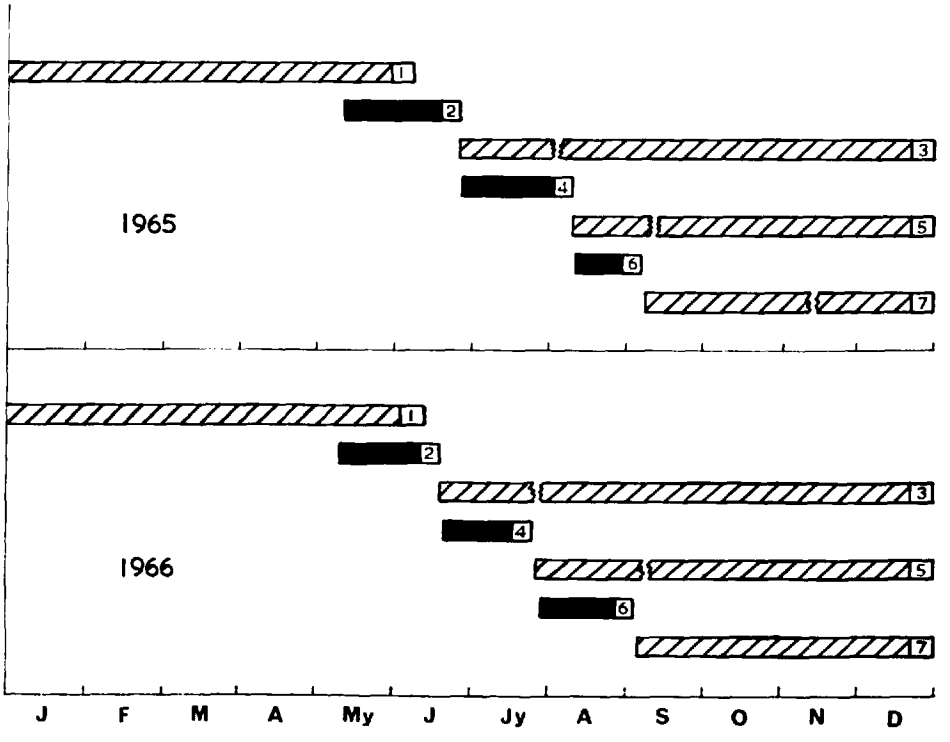


Fig. 78. Life history of Telenomus truncatus Mayr. in two seasons

1. Period of hibernation of females
2. Black blocks 2, 4 and 6 depict the 1st, 2nd and 3rd generations
3. Stencilled blocks 3, 5 and 7 depict adult periods of these generations

vegetation covered gorse bushes e.g. Rubus spp.

2. Number of Generations:

During 1965 and 1966, the number of generations of T. truncatus was studied in Yateley and at Silwood Park. The investigation and the host eggs which were placed in the field were similar to those described for Asolcus silwoodensis. In this way three successive annual generations were found to occur. Diagram (fig. 78) illustrates the life cycle of Telenomus truncatus in 1965 and 1966. The males of the first and second generation died by the middle of September and those of the third by the end of October. The females of the first and those of the second generation which had oviposited died after the oviposition period, but those which did not lay including those of the third generation aestivated and hibernated about one metre above the ground in the rearing cages.

3. Fecundity and Longevity of T. truncatus reared on old eggs of E. integriceps

The host eggs used in these observations were about five months old and kept at 2 - 3°C before being supplied to the parasites. Throughout their lives the Telenomus females were fed on a diet of honey and 3% sucrose solution.

These observations were made at 28°C and 75% relative humidity and breeding cages of No. 1 design were used. Each cage contained a pair of parasites bred at 25°C.

The results of these observations are shown in Table 55. The diet clearly prolonged their lives as the parasites under the same conditions did not survive more than seven days when they were fed on water only. The females lived longer than the males, but their fecundity appeared to be low.

Table 55.

Fecundity and Longevity of Telenomus truncatus Mayr, upon the five months old E. integriceps eggs, bred at 28°C and 75% R.H.

Pairs of parasites (replicates)	Longevity in days		No. of eggs supplied to parasites		No. of eggs parasitised				Total of parasitised eggs	% parasitism
					Parasites hatched		Parasites not hatched			
	Male	Female	Batch	Eggs	Male	Female	Male	Female		
1	32	36	8	96	0	0	1	4	5	5.2
2	30	24	8	94	2	0	0	0	2	2.1
3	23	39	9	99	0	0	0	0	0	0.0
4	27	41	7	86	0	0	0	2	2	2.3
5	26	28	9	102	1	2	0	3	6	5.9
Total and Averages	27.6	33.6	8.2	95.4	0.6	0.4	0.2	1.8	3	3.1

Parthenogenesis:

Similar to Asolcus spp. the females of Telenomus truncatus were able to lay parthenogenetically, the resulting progeny always being male. Mated females produced both sexes. All the females collected in the New Forest, Yateley, and tested in the laboratory, produced both sexes. This indicated that the females were normally fertilised in nature.

Sex Ratio and Factors Influencing the Sex of the Parasites.

The average sex ratio of male to female was 1 : 2 in T. truncatus. This sex ratio varied slightly in different hosts and in different generations of this parasite (see Table 56). The sex ratio was also different in the parasites collected from different localities, e.g. the sex ratio of the male to females of the parasites collected in the New Forest was 1 : 2.5 whereas in Yateley it varied from 1 : 1.3 to 1.8. The females produced males in early and in the late oviposition on a single host egg mass but the production of males also occurred in the middle of oviposition.

Host Specificity:

Telenomus truncatus is a polyphagous egg parasite of Pentatomoidea. In the laboratory it parasitised, developed and emerged from the eggs of all the shieldbugs studied in this

work. In southern England Piezodorus lituratus is its main host but it also parasitised the eggs of E. integriceps and P. bidens which were placed in the field at Yateley in May, June and July.

Superparasitism:

Among a large collection of the parasitised host eggs of P. lituratus collected at Cricket Hill in Yateley, only four eggs were superparasitised and each produced two females. They were able to emerge successfully. The parasites within each egg were head to tail and made two emergence holes on the host egg; one on the operculum and the other near the bottom. The size of the twin parasites was distinctly smaller than those of the normal females. The twin females also mated with the males of larger size and produced both sexes of normal size on eggs of P. lituratus and P. bidens. Successful superparasitism also occurred once in T. sokolovi but it was never observed in any superparasitised eggs of the Asolcus spp.

Distribution:

Telenomus truncatus is the most common egg parasite of Pentatomoidea in southern England. It was frequently collected in Yateley (Hants) and the New Forest. Several specimens were also collected in Wisley Common and in Silwood Park.

Percentage Parasitism in Eggs of Several Pentatomoidea by scelionid Egg parasites in southern England

1. Natural Parasitism:

During these studies an investigation was carried out to determine the natural percentage of parasitism in eggs of Piezodorus lituratus by scelionid egg parasites of the genera Asolcus and Telenomus. A random collection of egg masses of P. lituratus was taken from gorse during June 1965 and in May, June and July 1966 at Cricket Hill, Yateley (Hants). In the laboratory each egg mass was put in breeding box (design No. 1) at 22 - 23°C. The collections were examined daily for the emergence of parasites or hosts. The accumulated data based on the above collections, is presented in Table 56.

According to this Table in June 1965, 43.7% and throughout 1966 an average of 84.4% of eggs of P. lituratus were parasitised by four species of the scelionid egg parasites of the above mentioned genera. The data also indicate that T. truncatus parasitised an average of 67.4% of all the eggs in 1966 and 15.0% in 1965, thus T. truncatus Mayr is the most effective and dominant parasite of P. lituratus at Cricket Hill.

Percentage Parasitism in Eggs of Several Pentatomoidea by *Asolcus* and *Telenomus* Parasites at Cricket Hill, Yateley, (Hants).

Table 56. *Piezodorus lituratus* egg masses were collected from gorse (Natural Parasitism)

Date and species of host egg	No. of host eggs		Number of Parasites Emerged												Total Parasitised Eggs	Total Percentage of Parasitism
			A. nixo-martini				A. silwoodensis				T. truncatus				T. sokolovi					
	batch	eggs	♂	♀	Total	Parasitism	♂	♀	Total	Parasitism	♂	♀	Total	Parasitism	♂	♀	Total	Parasitism		
25.6.65	24	320	3	20	23	7.1	8	25	33	10.3	11	37	48	15.0	14	22	36	11.3	140	43.7
27.5.66	23	314	0	0	0	0	10	51	61	19.4	87	84	171	54.5	2	9	11	3.5	243	77.4
23.6.66	50	649	0	0	0	0	3	24	27	4.2	147	288	435	67.0	8	35	43	6.6	505	77.8
22.7.66	18	212	0	0	0	0	2	12	14	6.6	53	118	171	80.7	3	20	23	10.8	208	98.1

Table 57. The host eggs were placed in the field from 25.5 - 25.6.65 on gorse and broom

E. integriceps	13	142	1	6	7	4.9	2	9	11	7.7	3	8	11	7.7	9	10	19	13.3	48	33.8
P. bidens	15	136	2	3	5	3.6	0	0	0	0	6	13	19	14.0	18	26	44	32.4	68	50.0

The average percentage of natural parasitism by Asolcus silwoodensis was 10.06% and that of T. sokolovi was 6.96% in 1966. In 1965 there was also 7.1% parasitism by A. nixo-martini. The data also indicate that the eggs of P. lituratus were never parasitised by the other two species of Asolcus, although both were collected by beating gorse and broom and sweeping the grasses of the same habitats.

2. Percentage Parasitism in Eggs of A. acuminata, E. integriceps, P. bidens and P. lituratus which were placed in the Field.

Attempts were also made to find out the percentage of parasitism by Asolcus and Telenomus spp. on the eggs of the above-mentioned Pentatomoidea at Cricket Hill and Silwood Park. The method used for this study was to expose the fresh and unparasitised egg masses of these shieldbugs on gorse, broom and grasses for a certain period of time in the field. The eggs needed for this work were obtained from mass breeding of the shieldbugs in the laboratory; these were stored at 2.-3°C before being used. After exposing these egg masses for about 20 days in the field, they were collected and examined in the laboratory as described earlier.

The results presented in Tables 57 and 58 and

Percentage Parasitism in Eggs of Several Pentatomoidea by *Asolcus* Parasites at Silwood Park

Table 58.

Plot A. "New Broom" The host eggs were placed in the field from 5.7. - 25.7.63 on broom

Host egg species	No. of host eggs		Number of Parasites Emerged								Total of parasitised eggs	Total percentage of parasitism
			Asolcus nixo-martini				*Asolcus silwoodensis*					
	batch eggs		Male	Female	Total	% Parasitism	Male	Female	Total	% Parasitism		
P. lituratus	10	124	2	14	16	12.9	0	0	0	0	16	12.9
The host eggs were placed in the field from 8.6. - 27.6.65 on broom												
E. integriceps	21	247	0	0	0	0	4	18	22	8.9	22	8.9
P. bidens	7	41	0	0	0	0	1	4	5	12.2	5	12.2
P. lituratus	4	65	0	0	0	0	7	31	38	58.4	38	58.4
Plot B. "Old Broom" The host eggs were placed in the field from 8.6. - 27.6.65 on broom and gorse												
E. integriceps	7	94	1	11	12	12.7	0	0	0	0	12	12.7
P. bidens	10	89	4	8	12	13.4	1	3	4	4.4	16	17.8
P. lituratus	12	206	27	83	110	53.3	5	5	10	4.85	120	58.15

Table 58. (continued)

Plot C "Silwood Farm:" The host eggs were placed in the field from 8.6. - 27.6.65 on broom and gorse.

Host egg species	No. of host eggs		Number of Parasites Emerged								Total of parasitised eggs	Total percentage of Parasitism
			Asolcus nixo-martini				Asolcus silwoodensis					
	batch	eggs	Male	Female	Total	% Parasitism	Male	Female	Total	% Parasitism		
E. integriceps	10	112	0	3	3	2.7	0	2	2	1.8	5	4.5
P. bidens	8	106	2	11	13	12.3	1	4	5	4.7	18	17.0
P. lituratus	12	138	1	3	4	2.9	1	8	9	6.5	13	9.4

Note:

1) From a series of over 100 egg masses of E. integriceps, A. acuminata, P. bidens and P. lituratus which were placed in Plots A, B, C, and in the North Gravel in late August and during September, 1965, only one egg mass of A. acuminata was parasitised in Plot B; the parasites emerged in the laboratory at 25°C on 18.9.65 and resulted in one male and seven females of Asolcus waloffae.

2) No egg mass was parasitised by Telenomus spp. or by Asolcus davatchii at Silwood Park.

indicate that 33.8% of E. integriceps, 50% of that of P. bidens were parasitised by two species of Asolcus and Telenomus in June 1965 at Cricket Hill, Yateley and that again here Telenomus spp. had parasitised a higher percentage of these eggs than did the Asolcus spp. According to Table 57 the percentage parasitism by A. nixo-martini was 4.9% and 3.6% of the eggs of E. integriceps and P. bidens respectively (in June 1965), and that A. silwoodensis parasitised 7.7% of the eggs of E. integriceps. The parasitism by T. truncatus was respectively 7.7% and 14.0% of the eggs of E. integriceps and 13.3%, 32.4% by T. sokolovi of the eggs of the two above-mentioned hosts. The total parasitism of the eggs of E. integriceps by the Asolcus and Telenomus spp. was 33.8% and that of P. bidens was 50%

At Silwood Park (see Table 58) the results were different and the Asolcus spp. were the most common scelionid egg parasites of Pentatomoidea. According to Table 58, the percentage parasitism in Plot A during July 1963 by A. nixo-martini was 12.9% of the eggs of P. lituratus. In the same area the percentages of parasitism by A. silwoodensis in June 1965, of the eggs of E. integriceps, P. bidens and P. lituratus were respectively 8.9%, 12.2% and 58.4%. In Plot B at the

same period of time, and on the same host eggs, the percentages of parasitism by A. nixo-martini and A. silwoodensis together were 12.7%, 17.8% and 58.15% respectively. This parasitism in a third area (i.e. Plot C) was 4.5%, 17.0% and 9.4% on eggs of E. integriceps, P. bidens and P. lituratus respectively. The percentages of parasitism by these two species are also shown separately in Tables 56 and 57.

The above data indicate that:-

1) Asolcus spp. are the dominant scelionid egg parasite of Pentatomoidea at Silwood Park.

2) There was a higher degree of parasitism in the eggs of P. lituratus in Plots A and B; in Plot C however, this parasitism was higher on the eggs of P. bidens.

3) Only one batch of eggs of A. acuminata was parasitised by Asolcus waloffae in Plot B.

4) No eggs were ever parasitised by A. davatchii, T. truncatus and T. sokolovi in Silwood Park.

The general conclusion is that the distribution of the parasites in southern England is patchy, with either the Asolcus or Telenomus species predominantly in different localities. It would be interesting to study the ecological factors that determine these differences in distribution.

Conclusions:

The following conclusions can be made from the data on the biology and ecology of six British telenomid egg parasites of Pentatomoidea:-

1) The important points in the bionomics and behaviour of four Asolcus and two Telenomus spp., as natural egg parasites of Aelia acuminata, Neottiglossa pusilla, Palomena prasina and Piezodorus lituratus were studied in as much detail as possible.

2) The adult, immature stages and the reproductive biology of both sexes of six species were described. Hypermetamorphosis occurs in the development of the four Asolcus and the two Telenomus species, the first instar larva being of the "Teleaform" type.

3) The developmental period was variable depending on the species, being 11 - 14 days at 28°C and 23 - 25 at 20°C in Asolcus waloffae sp.n., A. nixo-martini sp.n., A. silwoodensis sp.n., Telenomus truncatus Mayr and T. sokolovi Mayr. This period appeared to be 28 - 32 days at 28°C and 60 - 70 days at 20°C in Asolcus davatchii sp.n.; such prolonged duration of development has not been previously recorded in telenomid parasites of the two above genera.

4) All six species of parasites have the almost perfect discriminative ability of attacking the healthy, and unparasitised host eggs. The females of both Asolcus and Telenomus spp.

normally oviposited only one egg per host; superparasitism rarely occurred and resulted in one or non in Asolcus emerging. Successful development and emergence of two females of Telenomus spp. from a single egg of P. lituratus was observed on several occasions under natural conditions. This has not been previously recorded in these parasites.

5) The females of both genera easily recognised the males of their own species by means of their antennae, and mated only once in their lifetime, usually immediately after emergence from their host eggs. All attempts to cross the different species of these parasites were unsuccessful.

6) Agressive behaviour i.e. fighting between the females for host eggs during oviposition, and among the males for the egg mass in order to patrol it and to fertilise the females on their emergence, was observed frequently in the field and in the laboratory. However, both sexes of T. sokolovi exhibited this behaviour less often than the other species. Marking of host eggs by females of the six species often occurred after successful oviposition.

7) Virgin females of the six telenomids reproduced parthenogenetically, the resulting progeny being male only; mated females produced both sexes with a higher ratio of females. The preliminary study on sex ratios indicated that the ratio of males to females was 1 : 4, 1 : 5 and 1 : 6 in Asolcus spp.

and 1 : 2 in Telenomus spp.; however, this ratio, was variable in all species under different environmental, host and food conditions.

8) The parasites were collected from different habitats. In this connection there was a relationship between the parasitic species and its pentatomoid host; A. waloffae was collected in grassland, A. silwoodensis and T. truncatus were collected on gorse and A. nixo-martini, A. davatchii and T. sokolovi in both habitats, as well as on broom.

9) Host specificity was also exhibited by two Asolcus spp., i.e. A. davatchii and A. waloffae parasitised only 2 - 3 species of eggs of Pentatomoidea, whereas the four other parasites were polyphagous and parasitised the eggs of more than 10 species. In the laboratory the eggs of E. integriceps were parasitised by six British telenomids, but, from a large number of egg masses of this pest placed in various fields in southern England, only four polyphagous species were obtained. The results of the experiments on host specificity of these parasites indicated that under standardised conditions in the laboratory A. waloffae parasitised 87% of the eggs of A. acuminata and 5.5% of E. integriceps.

10) The natural percentage of parasitism of eggs of P. lituratus was studied at Yateley and at Silwood Park in 1965 and 1966. The percentage of parasitism was very high in both years.

11) In the field and in the laboratory, longevity, fecundity and the percentage of parasitism in Asolcus and Telenomus spp. were studied, particularly in relation to differences in food, hosts and temperature. From the data so obtained it was concluded that the above factors directly affected the longevity, fecundity and the percentage of parasitism inflicted by these parasites on their hosts.

12) The number of annual generations of parasites differed in various species. Asolcus davatchii was univoltine, A. waloffae produced two generations a year and the other species were trivoltine. A. silwoodensis however, produced four generations in 1965. The adults of both sexes overwintered in clumps of dry grasses, under a bank of trees near the ground, or in other sheltered places; the males of all species died during the winter; the females and usually those that fed on honey dew survived until the next Spring.

13) The time of emergence of the overwintered females in the field varied from year to year and was variable in different localities. T. truncatus and A. silwoodensis appeared as early as the end of April in the New Forest and in Yateley, but about two weeks later at Silwood Park. A. davatchii, A. nixo-martini A. waloffae and T. sokolovi usually occurred towards the end of May and in early June. All species were collected in June and July and were very active during warm and sunny days. The

parasites disappeared from the breeding areas by the end of August and during September.

14) The study of comparative biology of the closely related British and other species helped to separate the extremely close species.

15) Eggs of Picromerus bidens were found to be suitable as host eggs for breeding these parasites throughout the year in the laboratory. Eggs of this predacious pentatomid have not been used earlier, in spite of this host's wide distribution throughout most of the palearctic region.

16) Satisfactory methods for breeding these parasites in the field and in the laboratory were devised; these methods could be used to study many other similar insects.

17) It is concluded that the distribution of these parasites in southern England is patchy and localised. It would be interesting to study the ecological factors that determine this patchiness in distribution.

18) It is suggested that breeding on the following species should be tried experimentally on the eggs of Pentatomoidea mentioned below:-

Parasite spp.		Host egg spp.
1) Asolcus nixo-martini sp.n. A. silwoodensis sp.n. Telenomus truncatus Mayr	on	Eurygaster integriceps
2) Asolcus waloffae sp.n.	on	Aelia spp.

Also it would be interesting to study the effect of the first three parasites on eggs of Nezara viridula L.

19) The ecological background of these parasites may determine whether they can be used with success in biological control. Availability of suitable aestivation and hibernation sites with bushes and trees near the breeding areas of the parasites is important in the maintenance of their high numbers.

20) As the above data on the British Asolcus and Telenomus spp. is new, it is realised that it is as yet very incomplete.

DISCUSSION

SECTION I

DISCUSSION ON PENTATOMOIDEA

The comparative biology of six pentatomid species of the genera Aelia, Eurygaster, Neottiglossa, Palomena, Piezodorus and Picromerus have been studied. The results of this comparative study concern the following topics:-

1) Seasonal changes in the population of A. acuminata, P. lituratus.

2) Fecundity in relation to food, temperature, crowding and mating.

3) Comparative morphology of the reproductive organs of six species of shieldbugs.

4) Diapause and migration in Pentatomoidea.

5) The effect of the scelionid egg parasites on the population of their pentatomoid hosts under natural conditions.

As mentioned in the introduction, up to now, very little is recorded on the biology and ecology of Pentatomoidea in Britain. The reason for this may be that these insects are of no economical importance in this country. As a contrast, several of these shieldbugs cause an important reduction of cereal and other crops in some regions of their distribution (Boselli, 1932; Tischler, 1937-39; Puchkov, 1961; Voegelé, 1961).

The non-British species, i.e. E. integriceps, is well known as a very serious pest of wheat and barley in southwest Asia and particularly in the Middle East (Fedotov, 1943-60; Alexandrov, 1947-48; Vodjdani, 1954; Brown, 1962-66; Martin et al. 1960-64;

Remaudière et al, 1960-63). A brief account of earlier work on these insects by the above mentioned authors and others, is given in the appropriate sections.

The aim of the present survey was to study some of the Pentatomoidea from different genera, and in particular those of economic importance, such as Aelia and Eurygaster, in order to learn "whether the results obtained can be generalised."

The study of P. bidens was primarily an attemtp to find out if its eggs can be used in rearing the scelionid parasites, since this was not known previously. Fortunately, the results were successful, not only because the eggs of this carnivorous pentatomid proved to be suitable for rearing many scelionid parasites throughout the year, but also because the study of its biology provided much understanding of the Amyoteinae in comparison with the phytophagous species and in clarifying certain controversial views in literature.

Broadly speaking, all insect populations are affected by their environmental factors. These are climatic, the habitat, food, and interspecific effects of other organisms (Uvarov, 1931; Tischler, 1937-39; Allee et al, 1949; Andrewartha and Birch, 1957; Richards, 1961). There are also some unknown physiological causes that may affect insect abundance.

The effects of the environmental factors on reproduction of Pentatomoidea were studied because of the practical and theoretical consequences of interference with fecundity and multiplication which determine the population of any species.

Some of the ecological characters of the overwintering sites and areas where the insects were actually found to feed, breed, aestivate or hibernate, were studied. Vegetation (i.e. host and food plants) and certain climatic factors such as temperature, relative humidity, and, to a lesser extent, the effect of rain, sun and wind on shieldbugs were investigated. Attention was paid to the microclimatic conditions under the shelter of grasses, plants, or on the food plants.

Among the climatic factors, temperature influenced and determined most activities in Pentatomoidea. The insects were able to adapt themselves to the changes of temperature ranging from -14°C in winter, to 29°C in summer in southern England. The adaptive behaviour in these, or many other species of insects, to microclimatic conditions and particularly to temperature during their life cycles, have been mentioned by many other authors (Butler, 1923; Makhotine, 1947; Peredel'skiĭ, 1947; Arnol'di, 1955; Andrewartha and Birch, 1955; Richards and Waloff, 1954-61; Johnson, 1966).

Rain, when it fell continuously, retarded the activities of the insects. Long periods of high humidity over 90% under shelters in grasses in winter caused mortality in all species. Long periods of low temperature and rain in spring 1964 affected the numbers of Piezodorus and Aelia and they were lower than in the other seasons. Some overwintered adults in breeding cages were also killed by these factors before they oviposited, whereas the same species were able to survive lower temperatures in the winter months. This has also been pointed out in some other insects which overwinter as adults (Barrett, 1882;

Uvarov,1931; Larsen, 1949; Andrewartha, 1963). Thus temperature greatly influences movement, feeding, and fecundity of these insects.

Generally, the number of Pentatomoidea collected were very low. Maximum numbers were collected in Yateley. At Silwood, the maximum no. of overwintered Piezodorus collected by 100 beats of eighths of bushes was 13, 15 and 14 between 1963 and 1965. The corresponding numbers of larval instars were 52, 37 and 14. The maximum numbers of overwintered adults of Aelia caught by 100 sweeps was 6, 44 and 37 in June 1964, 1965 and 1966 respectively. The corresponding numbers of their larval instars were under 50 during the three seasons. At Yateley, the number of adults and nymphs of P. lituratus on gorse and A. acuminata on grasses (similar to those at Silwood) was over twice as great as at Silwood Park. The number of Piezodorus on gorse in some areas of the New Forest and in Kent was even higher than that in Yateley. For example, on 14.8.65 at Queen's Bower in the New Forest, 92 instars and 9 adults of the new generation of P. lituratus were collected in a 100 beats of gorse. It was very interesting to note that in some areas with small or large patches of gorse, and broom with undergrowth of grasses in southern England, Scotland and Wales, no Piezodorus, Aelia, or any other expected shieldbugs, were ever found in over 100 beats or sweeps. This does not confirm Southwood and Leston's (1959) view, who say "P. lituratus is widely distributed in Britain and occurs wherever gorse is found." Besides the presence of food plants, other ecological factors may be important. These, however, were not studied.

Among the natural enemies, the minute scelionid egg parasites probably formed the major impact on the population of Pentatomoidea in southern England. These minute wasps are discussed later. Some other organisms reduce the number of shieldbugs; these include certain species of predators belonging to Acarina, Staphylinidae, Carabidae. Dipterous parasites and Nematodes probably attack Pentatomoidea. Birds are also known to feed on these insects, but no observations were made on them in this work (page 175).

Food has a remarkable effect on fecundity, longevity, rate of development and survival of the shieldbugs. The effect of food on survival and reproduction has been extensively studied in E. integriceps by the Russians (Fedotov, 1947 - 60; Ouchatinskaia, 1955; Vinogradova and Shumakov, 1958). This relationship in Eurygaster is so clear that it enabled Fedotov and his collaborators to establish a method of forecasting the strength of invasions of this pest by a quantitative estimation of fat during hibernation. This was confirmed by Brown (1962) and also in Nezara viridula L. studied by Kiritani et al. (1963) in Japan.

The effect of food was considerable on the six species of Pentatomoidea studied including E. integriceps. The effects on fecundity of food, temperature, crowding and mating has been studied in some detail, both in the phytophagous and carnivorous species. It was concluded that A. acuminata, E. integriceps and N. pusilla lay more eggs, their larvae suffer a lower mortality, and that ovarial development is more rapid at the high temperature of about 28°C (pages 80, 102 and 109.

On the contrary, both P. litunatus and P. bidens have higher fecundity and longevity at lower temperatures of about 23°C (pages 144,162). This probably bears on the distribution of these insects and on the status of the former species as pests of cereals in sub-tropical climates and will be discussed later.

Food clearly affected fecundity in species living on cereals. Fecundity and longevity were much higher on grain of wheat, and barley and water than on the green shoots (pages 106, 112). This confirms Martin's et al. (1963) conclusion. In contrast to the above authors, fecundity in the present work was estimated not only on the number of batches but also on the total number of eggs laid by a female.

Fecundity of Aelia and particularly that of E. integriceps on barley grain and water was slightly lower than on wheat (pages 102,109). This indicates that these insects feed and breed well on barley grain as well. The nymphs of all cereal species also feed and develop on both barley and wheat grain and water, but there were indications that development of larvae was more rapid and mortality was lower when they were reared on wheat. The fecundity of Eurygaster, however, on shoots of wheat was much higher than on those of barley. This is interesting because in the field the insect mainly attacks wheat cultivations, even those close to barley fields.

In P. lituratus fecundity was higher on broom than on gorse. The average number of eggs per female, and longevity, decreased at high temperature. In the field, fecundity of Piezodorus varied in different seasons and in different plants. The average number of

eggs per female was 148.5 on broom and 42 on gorse. Thus fecundity on broom is much higher than has been supposed by Boselli (1932). In the laboratory, fecundity on broom was 44.9 and 38.9 at 20° and 28°C respectively.

Fecundity in P. bidens in the field was 129.15 eggs per female in 1964, and 217, 257 and 108.8 eggs per female at 20°, 23.5° and 28.5°C respectively in the laboratory. At low temperatures this species lived a very long time but in the field all the adults died before early winter. The reduction of fecundity in insects in relation to crowding has been pointed out by many other authors (e.g.Norris, 1963; Birch, 1951). In Piezodorus, Aelia and particularly in E. integriceps fecundity decreased when they were crowded and fed on barley, or on wheat (page 116). This is because the extra number of insects were seen to interfere with the oviposition of the females. In Picromerus crowding increased fecundity to a certain level. The adults and larval instars of Pentatomoidea in southern England were sparse and did not compete for food and space; but competition seems to affect fluctuation of populations of Eurygaster (Fedotov, 1960; Martin et al, 1962-63).

Water as a component of environment is extremely important in development, breeding, fecundity and longevity of cereal shieldbugs and of Picromerus. References in support of this statement are given by Tischler (1937-39) and on E. integriceps by various authors (Vinogradova and Sumakov, 1958; Remaudière et al, 1960-62; Martin et al, 1960-64; Brown, 1962).

It is often stated that the fecundity and number of eggs per batch is related to the number of ovarioles and also to mating in these insects (Boselli, 1932; Peredel'skiĭ 1947). Unmated females of E. integriceps mature and oviposit but their fecundity is reduced (Martin et al, 1962-63). In the present study this was investigated in more detail. In all of the six species there was a pair of ovaries, but the number of ovarioles differed. The lowest number of ovarioles in each ovary is 5 in N. pusilla, whereas A. acuminata has 6, and E. integriceps, P. prasina, P. lituratus and P. bidens have seven. In the male a pair of ovoid, or somewhat round testis is common to all species, but the number of accessory glands are different.

The number of eggs in each batch varied in the above species. In Aelia, Eurygaster and Neottiglossa the more common number of eggs per batch was 12, 14 and 10, and this is related to their number of ovarioles. In N. pusilla 10 was the most common number of eggs per batch. Southwood and Leston (1959) , . state that this number is approximately 12, but this number was extremely rare. In P. prasina the number of eggs per batch was 28 in the early part of oviposition and 14 in its late part. Variability in the number of eggs per batch in P. lituratus was very common. Batches of 28, 21 and 14 were laid in early, and 7, 5 and 3 near the end, of oviposition. In P. bidens this number was extremely variable, ranging from 4 to 73, but there was a tendency to lay batches of about 30 - 40 in early oviposition and lower numbers down to 2 towards the end.

Breeding and rearing of the five phytophagous species and P. bidens was carried out both in the field and in the laboratory.

The method devised in the present work can be applied to most Pentatomoidea of other genera, not only those that feed on leguminous plants but also for rearing carnivorous species.

The presence of grain, or of seeds of food plants is essential for larval development of all phytophagous species and also serves as food reserve of the newly emerged migratory species. This was also pointed out in E. integriceps by Vinogradova and Shumakov (1958) and some others.

Investigations on Picromerus indicated that this pentatomoid is entirely carnivorous. It can be bred and reared to the adult stage on insect larvae and water only. There is no preference of diet, but thin-skinned larvae of smaller size of Lepidoptera and Coleoptera are more easily preyed on (see also Schumacher, 1910-12; Strawinski, 1927; Mayné and Breny, 1948).

In the Pentatomoidea studied, the first instar larvae do not feed, but probably they absorb water from their environment. All species were reared from eggs to adults both singly and in cultures, in the field and in the laboratory. In all cases the rate of development was slower in isolated larvae than in those kept together. In cultures larval development was more rapid, but their weights decreased when they were very crowded. In E. integriceps reared in crowded conditions some of the fourth and fifth instar larvae were affected and killed by some unknown disease (possibly bacterial).

Unmated females of all species were able to mature and lay, but their fecundity was lower than in mated females. Mating behaviour

is similar in all species to that in E. integriceps (page 96). Multiple copulation is common in Pentatomoidea. In five phytophagous species the female mates 3 - 4 times in her life, but this varies from 1 - 8, depending on the species, food and temperature. In E. integriceps the fecundity of females mated only once was almost the same as in females mated repeatedly, whereas in P. bidens the stimulus of copulation and presumably the presence of sperm, results in higher fecundity. This carnivorous species mated 5 - 7 times in her life, usually once before each oviposition. In some other Heteroptera such as Dysdercus fasciatus Sign. the females mature and lay without mating, but fecundity is lower than in females which copulated once in their lives (Hodjat, 1963). In some insects such as Glossina (Mellanby, 1937) and Dermestid (Ladduwahetty, 1962) oviposition does not occur without copulation.

Several females of different genera failed to lay in the field and in the laboratory, although they copulated. This was more usual in A. acuminata and E. integriceps when they were cultured at 20°C, whereas at 28°C this was very rare. Contrary to this, there were indications that females of Piezodorus and particularly of Picromerus failed to lay at 28°C although they mated 2 - 6 times. In most of these cases, non-ovipositing females had oocytes and eggs in their ovarioles. Therefore, it seems that some unknown physiological factors are involved which possibly are governed by temperature. Possibly spermatogenesis is retarded (Norris, 1934). These females usually lived longer than the ovipositing females.

In southern England all species of these Pentatomoidea are univoltine; the phytophagous species hibernate as adults in a state of reproductive diapause, whereas P. bidens overwinter in the egg stage. The three years of study on Picromerus does not support Southwood and Leston's statement of "a possible secondary cycle involving overwintering as larvae," because the larvae certainly die in early winter. Dupuis (1949 - 1952), reports that both P. bidens and P. lituratus are bivoltine in Morocco and possibly in southern France. Eurygaster integriceps is univoltine in all latitudes (Peredel'skiĭ, 1947; Vodjdani, 1954; Brown 1962 - 66).

Another interesting point about Pentatomoidea is dispersal which occurs in three ways:-

(1) True migration (E. integriceps; P. lituratus).

(2) Flight for short distances (A. acuminata; N. pusilla).

(3) Walking, or possibly flight (P. bidens).

It is generally accepted that newly emerged cereal shieldbugs such as Aelia and Eurygaster leave their birthplace and migrate (apparently flying with the wind) to the high mountains surrounding their breeding habitats (Achard and Adle, 1927; Zwölfer, 1930; Arnol'di, 1955; Voegelé,(1961),Brown 1962 and 1965). In some other species, as in Palomena, Piezodorus, the insects mainly migrate to forests, or woodlands, around their breeding sites (Butler, 1923; Boselli, 1932; Tischler, 1938 - 39; Puchkov, 1961), and finally, some species such as A. acuminata may fly to both mountains or to nearby woodlands.

In all three cases both sexes are sexually immature before, in, and after migration to their aestivation sites. The reason for this migration, either over a long distance (about 25 km in E. integriceps) or shorter (less than 25 km in Aelia, or Piezodorus) results in aestivation in cooler climate (Fedotov, 1947 - 60; Brown, 1962 and 1965). Both in sub-tropical and temperate climates these insects aestivate for about 2 - 4 months in late summer and early autumn, either under bushes in high altitude on mountains, or on trees in woodlands. In early months of autumn after a cool period and rain, they again migrate, or fly down to lower altitudes, usually on the southern slopes, and hibernate under bushes on mountains, mostly in sub-tropical regions. In the temperate species e.g. Piezodorus, the adults fly to the ground level and hibernate under grasses or leaves. In certain species both types of movement may occur, as in A. acuminata, but distance of flight is shorter than in sub-tropical and temperate climates.

All these insects aestivate and hibernate until the rise of temperature in spring which stimulates them to migrate again to suitable habitats where they feed, mate, oviposit and multiply. The overwintered bugs then die, (Tischler, 1937-39; Puchkov, 1961). There are many other species of Pentatomoidea of other genera, for instance Carpocoris and Dolycoris which have similar life cycles (Butler, 1923; Boselli, 1932; Southwood and Leston, 1959; Brown, 1966).

In almost all cases aestivation and hibernation periods are in an "adaptive phase" of obligatory reproductive diapause until the beginning of favourable conditions in spring. In both sexes, feeding

in spring is essential before the first mating and oviposition in both the migrated or non-migrated individuals. Possibly Southwood (1960) is mistaken in saying that "Pentatomoidae engage in less flight activity than some other families of shieldbug - Cydnidae and possibly Acanthosomidae." This statement is perhaps due to the fact that up to now very little is known about dispersal of Pentatomidae which are not economically important.

Recently migration in insects has been discussed by many authors on the basis of a theory put forward by Johnson(1960). He pointed out that "mass migration begins in the first place either as first flights at the end of teneral period or soon afterwards." Since 1960 much evidence linking migration with the post-teneral period has been collected (Kennedy, 1961; Schneider, 1962). Johnson (1963, 1965) suggests that "neurophysiological processes are responsible for the characteristic migratory flight of insects, because the factors which prolong sexual maturity appear to evoke and prolong migration in females." As regards Pentatomoidea of the genera Aelia and Eurygaster it was recently stated (Brown, 1965) that migration in these insects could be specified as "pre-reproductive" rather than "post-teneral" (Kennedy, 1961). Johnson (1966) reviewed the existing literature and says that now there are two hypotheses for the cause of adaptive dispersal:- " One that adults respond immediately to adversity by flying away; another that adversity and the factors heralding it, act ontogenetically to produce adults that are prone to migrate (Johnson, 1963); that migratory flight is a symptom in an endocrine deficiency syndrome concomitant

with early adult life and ovarial immaturity, ovarial diapause and structural polymorphism." The present observations seem to fit in with Johnson's second hypothesis. It is worth mentioning here that individuals of E. integriceps, P. lituratus and A. acuminata, which did not migrate, also mature sexually after the termination of diapause, but that the fecundity of non-migrants was lower than in the migrants. This supports Kennedy's suggestion (1961).

Diapause in Pentatomoidea can be divided into three forms (1) diapause in the egg stage, e.g. in P. bidens (2) during the larval period, e.g. in Pentatoma rufipes (3) in the adult stage, as in most shieldbugs, e.g. E. integriceps. All three forms were observed in this work. It was concluded that diapause in Picromerus can be broken by subjecting the eggs to low temperatures for about 30 days. No conclusion was drawn from the observations on the larvae of P. rufipes because all larvae collected died in the laboratory. More attention was given to diapause in the adults. The test insect was E. integriceps, but some work was also carried out on this topic in A. acuminata and P. lituratus. The results indicated that E. integriceps and P. lituratus have a long diapausing period. In Eurygaster, diapause is influenced by both photoperiodism and temperature (page 86) and in Piezodorus it is characterised by an apparant colour change on the dorsal parts of the body (page 137).

Some fundamental physiological features in insect diapausing as adults include (1) strongly reduced basal metabolism (2) low water content and high fat content and (3) standstill of morphogenesis (Wilde, 1954; Lees, 1955; Danilevskii, 1965). Norris (1963) stated that

"Reproductive diapause initiated by token stimuli and terminated by the onset of ameliorated conditions as a particularly effective method of timing the life cycle." Wilde (1962), further says "in insects, all stages, except the pupae, may be sensitive to photoperiodism."

Up to now, all attempts to break diapause in some insects including that in E. integriceps have failed. Thus, in spite of a remarkable physiological (Fedotov, 1947-60; Brown, 1962) and biochemical (Strogaia, 1955) work on Eurygaster, it appears that there is much more to study. The preliminary results obtained in the present work suggest that the physiology of diapause in Eurygaster integriceps is governed by both photoperiodism and temperature.

Another interesting topic mentioned at the beginning of this study is on "factors which favour mass multiplication of shieldbugs." It is realised that from only three years of study, little can be said, although certain major factors were examined in some detail in species from different climatic regions. Obviously high temperature is important to E. integriceps (pages 105 and 111) but affects the temperate species adversely. Further, the scelionid egg parasites have an effect on the numbers of their hosts.

Finally, the degree to which scelionid egg parasites of Pentatomoidea can be effective in controlling the population of these insects, depends on the environment in which the host species lives as well as on the species of the parasite. Generally, it can be concluded that both Asolcus and Telenomus are more susceptible to unfavourable conditions than their pentatomoid hosts. The percentage of egg parasitism

in a temperate climate as in Britain, or in sub-tropical climate as in Iran is usually low in the first seasonal generation of the parasites but higher in the others (see Martin et al., 1962-64).

Biologically, the life cycle of the hosts and parasites are synchronised, but in both countries the numbers of overwintered female parasites are too low to be able to cope with their hosts in early oviposition. On the other hand, the climatic conditions also favour Pentatomoidea more than their egg parasites, even in the second generation of polyvoltine wasps. Further studies are needed to find out whether egg parasitism inflicted by the first generation of wasps can be augmented. Figure 80 shows areas of disitribution of Eurygaster and Aelia with their scelionid egg parasites of the genus Asolcus in different altitudes and climatic conditions in Iran.

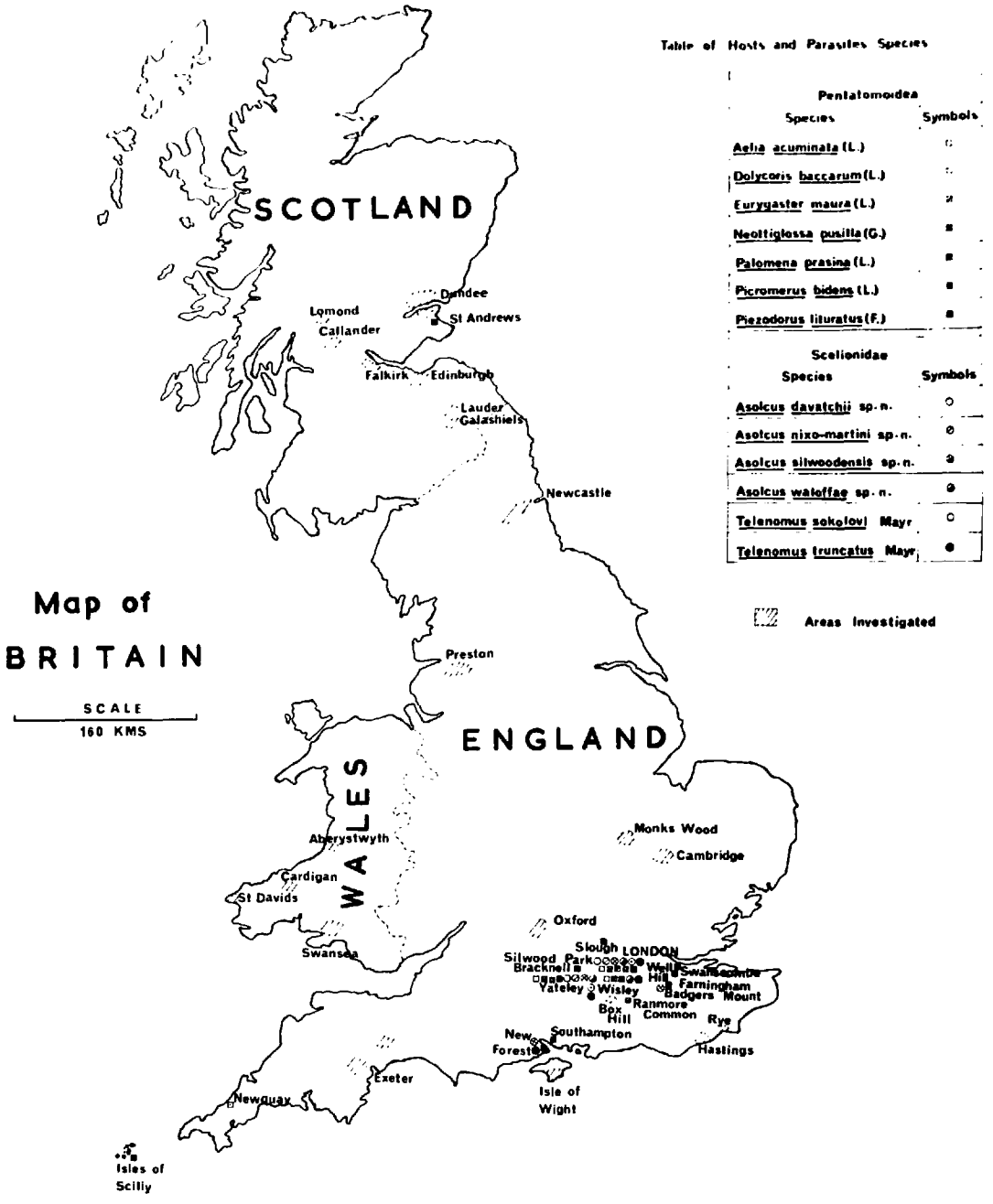


Fig. 79. Map of Britain showing Localities in which Pentatomoidea and their Scelionid Parasites have been Collected and Studied

S E C T I O N II

DISCUSSION ON HYMENOPTEROUS PARASITES

Judging by the available literature, no previous attempts have been made to study the scelionid egg parasites of Pentatomoidea in Britain.

During the present study, six species of these proctotrupoid egg parasites were collected in southern England. As this study was mainly focussed on the biology of both shieldbugs and on their hymenopterous parasites, the discovery of these parasites provided an opportunity to carry out an original and detailed investigation on these topics. In practice, it also became necessary to study in detail, the taxonomy of all scelionid egg parasites of Pentatomoidea of both genera Asolcus and Telenomus collected from various countries in the world in an attempt to identify the British species.

The main investigations were carried out on these parasites and particularly the following aspects are briefly discussed below:-

1) Localities where the six British telenomids were found.
2) The methods which were devised for their study.
3) The difficulties in determining the taxonomic status and the methods that were used to identify the species.
4) The biology, behaviour and life histories of these parasites both in the field and in the laboratory.

5) The percentage of parasitised pentatomoid eggs in the field.

6) The relationships of these parasites with the species of the same genera found abroad.

In the light of the data obtained on the six species, an assessment is made as to whether they are promising material for biological control of pentatomoid pests.

Indeed, our knowledge of the biology, ecology and taxonomy of some species of the scelionid egg parasites has greatly increased in recent years, and fortunately, in some countries, considerable attention has been paid to several species of these parasites. In this connection a brief review of the literature has been given at the beginning of this section.

As mentioned in the introduction, the study of these economically important parasites has been neglected in Britain; the data therefore, given here, are original and were obtained during the course of the three years work at the Imperial College Field Station.

A map of Britain (Fig. 79) has been included to illustrate the areas which were studied and the localities in which each of the Asolcus and Telenomus spp. were collected. It must be remembered that this presents only an introduction

to the distribution of these scelionids in Britain and was prepared to guide entomologists to further studies in this field.

According to this map, all the six species of telenomid parasites have been collected in the southern areas of the Thames valley. The distribution of all Pentatomoidea collected during the course of the present investigation are also shown. It is interesting to note the relationships between the hosts and the parasites in various localities, as well as the patchy distribution of these Asolcus and Telenomus spp. and their hosts in southern England.

Ecologically speaking, from a comparison of the habitats in the areas studied in England, Scotland and Wales, it seems that the climatic conditions (particularly so far as temperature is concerned) host plants and the abundance of the aestivation and hibernation quarters near to the breeding fields, are the most important factors for the distribution of these parasites and their hosts. The effect of such factors on the distribution of the species has been generally accepted (see Barrett, 1882; Uvarov, 1931; Elton, 1933; Tischler, 1937 - 61; Birch, 1957; Nicholson, 1958; Richards, 1961). There may, however, be some other factors involved, i.e. unknown physiological requirements of the species (see Fedotov, 1947 - 60; Brown, 1962; Johnson, 1966).

In studying any of Asolcus and Telenomus egg parasites of Pentatomoidea, the entomologists have always attempted to find a suitable host and a practicable rearing method for these minute wasps (Vassiliev, 1913; Boselli, Zwölfer, 1932; Tischler, 1938; Alexandrov, 1949; Voegelé, 1961). The reason is that these parasites are some of the smallest of all insects in the world and are very difficult to handle; and that most of their hosts are univoltine having a short period of oviposition each year. The known methods of culturing them (breeding in test tubes) were also inadequate, and a new one had to be evolved.

The above problems were effectively solved during this work. Instead of test tubes, round or rectangular boxes of transparent polystyrene were used. These varied in size, and were 1 - 2mm in thickness with ventilation windows and a relative humidity of about 75%, and were carefully designed. For handling, a special pooter was devised. These rearing boxes and the handling pooter were found to be most satisfactory. They were also found to be suitable for rearing other species of hymenopterous parasites of different families.

As host for culturing most of the Asolcus and Telenomus spp., the eggs of predacious Picromerus bidens were effectively used. The attempts to breed this species of Amyoteinae throughout the year in the laboratory, was successful.

The eggs of this host have never been previously used for culturing the telenomid parasites. The information on the biology of this pentatomoid and the method of its breeding has been given in the appropriate part. It should be mentioned here, that several well known Asolcus spp. such as A. semistriatus, A. grandis and A. vassilievi Mayr were also bred on the eggs of Picromerus. Thus, at last, a suitable host for easy culture of these parasites throughout the year was established in this work.

The identification of British Asolcus and Telenomus species became a very difficult taxonomical problem. This was because the systematics of the groups concerned were not in a satisfactory state (see Kieffer, 1926; Nixon, 1935-43; Masner, 1958; Delucchi, 1961; Viktorov, 1964; Voegelé, 1965). The finding of the six British species increased the difficulty of identification since some of them were closely related to species already described; they were also closely allied amongst themselves.

Dealing mainly with the biology of these parasites, all six species were carefully separated and sent to the British Museum with a request for their identification. Except for one Asolcus species, the other five Asolcus and Telenomus were identified as four already described species. One of the Asolcus was also identified as A. semistriatus at

F.A.O. Sunn Pest Research Centre in Paris.

The above determination of these parasites did not appear to be correct. Attempts were therefore made also to study their taxonomy. In this connection, nearly all known species of Telenominae, parasitising the eggs of Pentatomoidea in various countries, particularly in Iran, Japan, Morocco, New Zealand and Russia, were collected for a taxonomical comparison with the British species. For the closely related Asolcus species, the live parasites were also obtained and cross-breeding tests were attempted. All the Asolcus and Telenomus egg parasites of pentatomids deposited in the British Museum were also studied. On the other hand, the biology, ecology and reproductive morphology of the six British species were investigated in detail. Great pains have been taken to search for their true value. All characters which form the foundation for the systematic arrangement of the species, have been carefully investigated, in a large number of specimens bred on the different hosts and under different environmental conditions, as well as those received from other countries.

Thus, through a combination of biological and morphological characters of the British and the non-British species the identification key and descriptions of the species have been prepared. Outline drawings of all the important taxonomic characters have also been made.

According to my key there are four Asolcus and two Telenomus spp. in the British fauna of the egg parasites of Pentatomoidea. Four Asolcus have been described as new species; these are A. davatchii sp.n., A. nixo-martini sp.n., A. silwoodensis sp.n., and A. waloffae sp.n. The two Telenomus species have been accepted as T. sokolovi Mayr and T. truncatus Mayr. The two well-known Asolcus species A. semistriatus Ns (Delucchi) and A. grandis Thom. (Delucchi) have also been included in the above mentioned key, since their presence is essential for determination of these parasites.

The combination of biological and morphological study in the separation of the true validity of these parasites was found to be satisfactory in systematics of these hardly determinable hymenopterous parasites, and the title proposed for them is "bio-morphological taxonomy."

Turning to the biology, behaviour and life history of these parasites, reference should be made to other species of telenomids which have been studied in other countries (see Balduf, 1926; Jones, 1937; Kamal, 1938; Tischler, 1938; Schell, 1943; Hidaka, 1958; Wilson, 1961; Safavi, 1963; Martin et al, 1960 - 64; Voegelé, 1961 - 65; Hokyo and Kiritani, 1963 - 66; Cumber, 1964; Viktorov, 1964).

In this work the important points in the bionomics and behaviour of these telenomids were continuously studied

throughout three years both in and out of doors. A new method of culturing them continuously was found, detailed experimentation and observations on their biology was carried out. All stages of the four Asolcus spp. and two Telenomus species, i.e. eggs, larval instars, pupa, and adults, were described for the first time. Oviposition, agressiveness and mating behaviour were studied, in all the species, in as much detail as possible. The reproductive organs of both sexes of the six species were described. It was difficult to dissect these minute parasites successfully, since their internal organs are very delicate and are easily damaged by dissecting needles. Therefore, they were usually hardened by Kahle's solution and, later, were carefully dissected and drawn.

The voltinism of the six species in southern England was determined. According to these investigations Asolcus davatchii was univoltine, A. waloffae was bivoltine and the other four species were polyvoltine. It must be remembered that univoltinism in Asolcus species has not yet been recorded and is of much interest biologically.

The developmental period of Asolcus and Telenomus species was studied at various constant temperatures as low as 15°C and as high as 35°C. This period for A. davatchii being 27 - 32 days at 28°C and 65 - 70 days at 20°C. In the other five species of Asolcus and Telenomus this period was 11 - 14 days

at 28°C and 23 - 26 days at 20°C. The host species appeared to have no distinct effect on the developmental period, both in the field and in the laboratory. Three larval instars were found in all species; the first larva being "Teleaform" and that of the 2nd and 3rd were hymenopteriform.

The effect of temperature on the longevity and fecundity of all species was investigated. The results of these studies indicated that in all species of both genera, the highest number of eggs are laid within the temperature range of 26° - 28°C. This was also true in the field, since the parasites showed most of their activities at high temperature during the Summer months, particularly in July. All species of British and non-British telenomids lived longer at lower temperatures. The maximum record of longevity at 20°C was 147 days in a female of A. silwoodensis fed on honey dew and water throughout her life. The males of all species usually lived for a shorter period than the females. In the field, resistance of all species to low temperature was studied. There were indications that all males died in early winter, but the females survived and resisted a temperature as low as - 15°C. In the laboratory, the females survived up to eight months at 2 - 3°C in the breeding cages. In this connection Asolcus species were found to be more resistant to the changes of temperature than Telenomus spp. A. silwoodensis lived longer at various

temperatures. whereas T. sokolovi lived for a shorter period than the other species.

The effect of various foods, such as honey, honey dew, pollen and sucrose solution on fecundity and longevity were also studied. More experiments were carried out on A. silwoodensis and A. davatchii. The general conclusion was that the parasites lived longer, and fecundity was higher when honey dew was supplied as food, both in the field and in the laboratory. The females of all species were also able to mature and oviposit without any feeding. In the field the females which were fed on honey dew survived until the next spring.

The parasites of both genera had almost perfect discriminative in attacking the healthy, and unparasitised, host eggs. The females normally laid one egg per host, but super-parasitism also occurred (but rarely) in all species. This resulted in one or no parasites emerging from the host. In T. truncatus and T. sokolovi however, successful superparasitism was also observed in four eggs of P. lituratus collected at Yateley. Three of these eggs produced six females of the former species, and, from the other egg, two females of T. sokolovi emerged. Successful superparasitism in telenomids parasitising the eggs of Pentatomoidea was extremely rare and has not been recorded previously.

The females of all species recognised the males of their own species by means of their antennae and mated once only in their lives, immediately after emergence. The virgin females of all species produced males parthenogenetically, and mated females produced both sexes with a ratio of male to females of 1 : 5 in Asolcus and 1 : 2 in Telenomus spp. In mating, the size of both sexes did not appear to be of importance. Antennae, ant particularly the flagellum, were essential for mating and oviposition. All Asolcus and Telenomus studied were found to be arrhenotokous. The exception to this is T. nakagawai, which is deuterotokous producing females parthenogenetically (Hokyo et al, 1966).

The parasites normally emerged in the morning. The emergence holes were usually made on the operculum. There was a clear difference between the emergence hole made by Asolcus and those of Telenomus spp., as the former species made a round and larger hole for their emergence. Voegelé (1961) and Hokyo et al (1966) have reported the differences in emergence holes of several Asolcus and one Telenomus in the Moroccan and Japanese species of telenomid parasites.

The agressive behaviour of males in fertilising the females, and the females when they were short of host eggs for oviposition, have been mentioned in several species of these parasites. Wilson (1961) and Safavi (1963) reviewed the

relevant literature and further described adult reproductive behaviour in Asolcus. Hokyo et al (1966), in comparing the biology of two Japanese telenomids, described further the general bionomics of one Asolcus and one Telenomus species in southern Japan. All the British telenomids also showed the agressive behaviour mentioned above; it was interesting, however, to see that this behaviour was less frequent in T. sokolovi.

Viktorov (1964), on his study of the host selection of the Russian telenomids, says this character helps in separation of the species. Cumber (1964) and Voegelé (1964-65) who worked on host specificity of the New Zealand and Moroccan Asolcus species also discussed and reported that several species of Asolcus are host specific. In all British and three species of the Moroccan and Persian telenomids, it was also noticed that several species such as A. davatchii and A. waloffae were specific in their host selection. It was also interesting to note that A. grandis rarely parasitised the eggs of P. bidens, whereas the eggs of this predator were very suitable in culturing A. semistriatus and A. vassilievi Mayr.

In the field pentatomoid eggs were heavily parasitised. At Silwood Park the Asolcus species were more abundant, whereas in Yateley and in the New Forest Telenomus spp. were more common. T. truncatus however, was the most common species parasitising the eggs of P. lituratus in the

Southern part of the Thames valley. The percentage parasitism was lower in the first generation of parasites in June and was at its maximum (up to 98%) at the end of the oviposition period of P. lituratus towards the end of July and in August. During May and June, however, the parasites were not able to parasitise more than 65% of their hosts.

Finally, on the basis of the data obtained, and on the preliminary survey on these parasites for biological contro, it seems that A. nixo-martini, A. silwoodensis, A. waloffae and T. truncatus are promising species in this field. It would be interesting to find the effects of these parasites, experimentally, in control of pentatomoid pests in other countries.

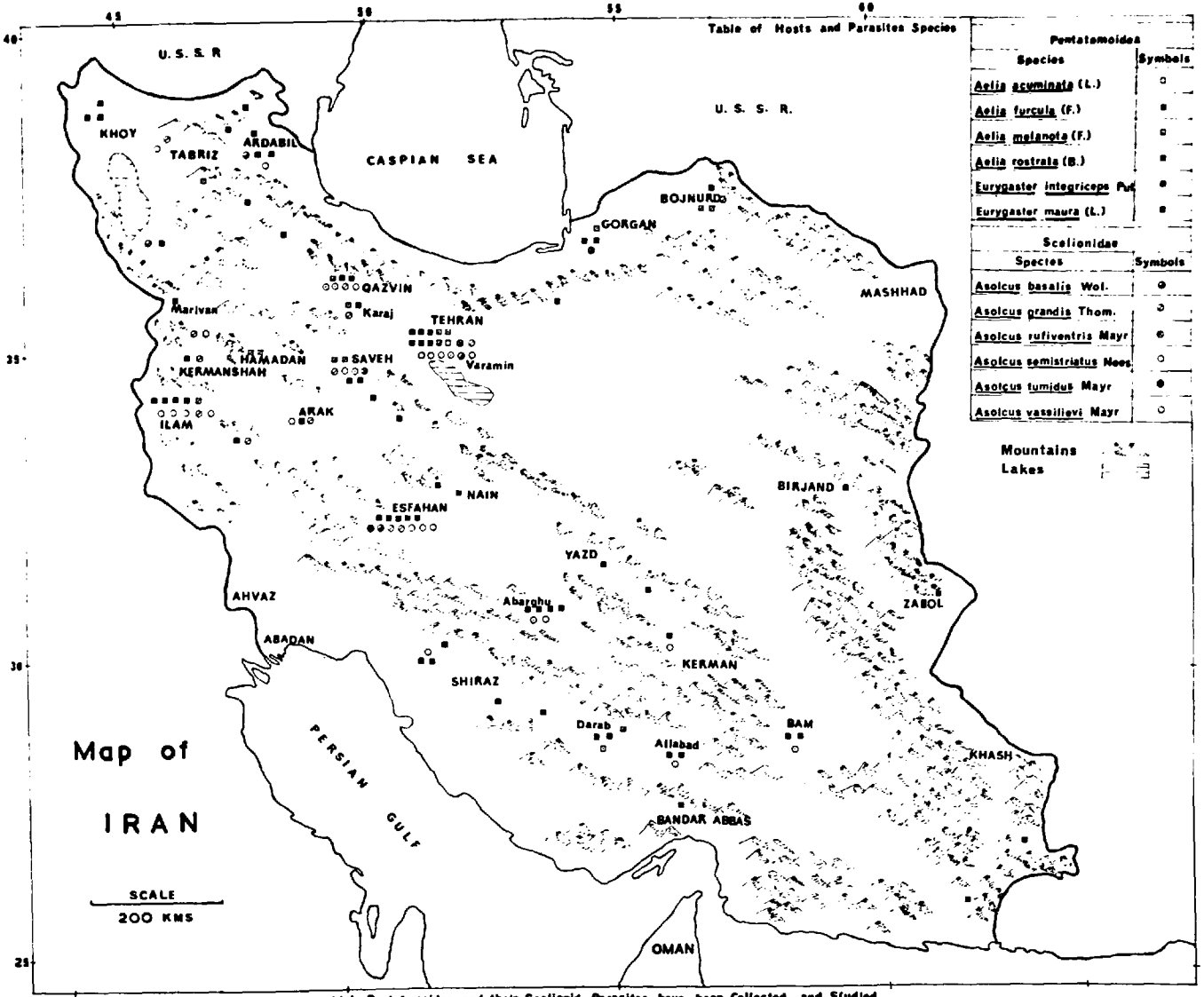


Fig. 78. Map of Iran showing Localities in which Pentatomoidea and their Scelionid Parasites have been Collected and Studied

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APPENDIX I. Fecundity, Longevity and Distribution of Oviposition Sites of *Aelia acuminata* in the field in 1965

Pairs (No. of replicates)	Longevity in days		No. of eggs laid by each female				Oviposition sites		
			No. of batches	Usual No. of eggs per batch	Limits of No. of eggs per batch Min.-Max.	Total eggs	No. of eggs laid on grass		
	Male	Female					Ears	Leaves	Stem and Muslin
1	27	58	0	0	0	0	0	0	0
2	39	122	9	12(8)*	7 - 12	101	84	17	0
3	37	30	1	12(1)	12	12	12	0	0
4	62	115	6	12(5)	11 - 12	71	0	48	23(S)
5	92	135	11	12(11)	12	132	96	36	0
6	38	74	8	12(6)	7 - 15	94	82	12	0
7	57	54	0	0	0	0	0	0	0
8	118	139	14	12(11)	7 - 12	161	143	0	18(M)
9	41	130	6	12(3)	11 - 13	70	46	12	12(M)
10	61	123	8	12(7)	5 - 12	89	17	72	0
11	68	78	8	12(7)	9 - 12	93	45	36	12(M)
12	57	65	7	12(6)	9 - 12	81	81	0	0
13	64	60	5	12(5)	12	60	48	12	0
14	43	58	6	12(4)	11 - 12	70	70	0	0
15	71	96	6	12(6)	12	70	70	0	0
16	59	56	5	12(6)	12	60	24	36	0
17	26	49	3	13(3)	12	36	36	0	0
18	32	112	10	12(10)	12	120	108	0	12(S)
19	104	136	3	13(3)	12	36	24	12	0
20	67	123	12	12(11)	10 - 12	142	70	72	0
21	120	144	7	12(7)	12	84	48	36	0
22	58	43	8	12(8)	12	96	84	12	0
23	112	128	6	12(6)	12	72	60	0	12(S)
24	42	47	6	12(6)	12	72	48	24	0
25	132	138	6	12(6)	12	72	72	0	0
Total and Average	65.0	92.5	6.4	12(5.8)	9.7 - 11.2	75.7	54.7	17.5	3.5

* No. of batches in brackets.

APPENDIX II. Fecundity, Longevity and Distribution of Oviposition Sites of *Aelia acuminata* bred at 20°C and 75% R.H; Food-wheat and barley grain and water

Pair No. (Replicates)	Longevity in days		No. of eggs laid by each female				Oviposition sites		
			No. of batches	Usual No. of eggs per batch (no. of batches in brackets)	Limits of No. of eggs per batch	Total eggs	No. of eggs laid on:		
	Male	Female					Cardboard	Muslin	Glass and Plastic
1	124	207	1	14(1)*	14	14	0	14	0
2	116	274	4	12(2)	12 - 20	45	12	33	0
3	91	279	3	12(2)	12 - 16	71	40	0	31
4	215	242	4	12(3)	10 - 12	46	0	46	0
5	12	274	3	12(2)	12 - 13	37	37	0	0
6	91	93	6	12(4)	5 - 12	60	12	48	0
7	83	307	2	10, 15	10 - 15	25	25	0	0
8	214	236	1	16	16	16	0	16	0
9	245	143	2	12(2)	12	24	0	12	12
10	68	222	1	5	5	5	0	5	0
11	91	235	3	12(2)	7 - 12	31	0	19	12
12	303	24	0	0	0	0	0	0	0
13	30	308	2	10, 20	10 - 20	30	0	30	0
14	61	30	1	12(1)	12	12	0	0	12
15	16	307	6	12(4)	10 - 13	71	23	48	0
16	90	288	4	12(4)	12	48	12	24	12
17	33	294	6	12(4)	4 - 12	60	48	0	12
18	252	24	1	12(1)	12	12	0	12	0
19	92	214	0	0	0	0	0	0	0
20	48	303	0	0	0	0	0	0	0
Total and Average	113.7	215.2	2.5	12(1.6)	8.9 - 11.4	30.3	10.4	15.3	4.6

* No. of batches in brackets.

APPENDIX III. Fecundity, Longevity and Distribution of Oviposition Sites of *Aelia acuminata* at 28.5°C and 75% R.H; Food-wheat and barley grain and water

Pair No. (Replicates)	Longevity in days		No. of eggs laid by each female				Oviposition sites		
			No. of batches	Usual No. of eggs per batch	Limits of No. of eggs per batch	Total eggs	No. of eggs laid on:		
	Male	Female			Min.- Max.		Cardboard	Muslin	Glass, Plastic
1	54	84	41	12(20)*	9 - 13	458	0	238	220
2	32	92	35	12(30)	11 - 15	419	24	253	142
3	63	26	18	12(18)	12	216	0	156	60
4	76	32	22	12(13)	7 - 15	250	12	192	46
5	75	54	30	12(25)	9 - 15	362	0	350	12
6	42	48	29	12(20)	5 - 16	359	0	158	201(P)
7	33	34	22	12(17)	6 - 15	249	12	123	114(P)
8	57	39	14	12(10)	10 - 14	167	12	155	0
9	63	65	42	12(36)	10 - 24	498	0	331	167
10	22	21	11	12(10)	12 - 15	135	0	135	0
11	45	68	45	12(43)	10 - 12	536	0	524	12
12	46	111	5	12(4)	7 - 12	55	0	43	12
13	63	74	53	12(44)	5 - 14	623	12	347	264
14	30	81	8	12(8)	12	96	0	84	12
15	71	83	36	12(23)	9 - 17	417	0	140	277
16	48	67	4	13(3)	11 - 12	47	23	24	0
17	51	33	5	12(5)	12	60	0	24	36
18	93	117	3	13(3)	12	36	0	24	12
19	47	42	21	12(10)	7 - 15	240	38	155	47
20	13	62	51	12(47)	8 - 12	604	36	486	82
Total and Average	51.2	61.6	24.7	12(19.4)	9.2 - 14.2	291.3	8.4	197.1	85.8

* No. of batches in brackets

APPENDIX IV.

Fecundity and Longevity of E. integriceps at 23.5°C and 75% R.H; food-wheat grain and water.

Pairs No. (Replicates)	Longevity in days		No. of eggs per female			
	Male	Female	No. of batches	Usual No. of eggs per batch	Limits No. of eggs per batch	Total No. of eggs
1	28	23	8	14 (8)*	14	112
2	32	16	1	14 (1)	14	14
3	18	20	5	14 (3)	11 - 14	66
4	37	26	8	14 (6)	12 - 16	112
5	28	43	8	14 (7)	5 - 14	103
Total and Average	28.6	25.6	6	14 (5)	11.2 - 14.4	81.4

* No. of batches in brackets.

APPENDIX IVa.

Fecundity and Longevity of Crowded E. integriceps at 28.5°C and 75 % R.H; food wheat grain with water. Level of Crowding: 10 pairs in each replicate

No. of Replicates	Mean longevity in days		No. of eggs per 10 females	
	Male	Female	No. of batches	No. of eggs
1	25.2	40.0	80	1005
2	15.7	23.5	126	1626
3	12.6	17.7	63	825
4	19.8	18.5	74	1001
5	20.2	24.5	122	1599
6	28.4	38.8	135	1783
7	16.7	15.0	76	1052
8	17.7	20.5	105	1471
9	21.1	19.8	48	682
10	21.5	23.4	103	1378
Total and Average	19.8	24.1	93.2	1242.2

APPENDIX V. Fecundity and Longevity of E. integriceps at 28.5°C and 75% R.H; food-wheat grain and water.

Pairs No. (Replicates)	Longevity in days		No. of eggs per female			
	Male	Female	No. of batches	Usual No. of eggs per batch	Limits No. of eggs per batch	Total No. of eggs
1	50	63	20	14(6)*	4 - 14	210
2	34	56	12	14(5)	7 - 14	144
3	32	69	21	14(14)	9 - 14	263
4	51	68	22	14(13)	3 - 14	265
5	30	33	10	14(8)	13 - 15	140
6	39	37	14	14(14)	14	196
7	51	57	19	14(17)	5 - 14	253
8	48	71	25	14(9)	5 - 14	274
9	19	41	15	14(9)	7 - 21	206
10	50	63	15	14(5)	6 - 14	182
11	38	57	22	14(8)	4 - 14	256
12	39	72	25	10(8)	3 - 14	292
13	36	43	18	14(10	7 - 19	244
14	25	37	13	14(9)	3 - 14	157
15	48	60	17	14(14)	3 - 14	219
16	36	37	10	14(10)	14	140
17	41	63	31	14(14)	2 - 16	338
18	50	75	2	14(1)	10 - 14	24
19	45	42	9	14(6)	8 - 14	112
20	9	37	11	14(5)	11 - 14	142
21	43	13	1	14(1)	14	14
22	45	43	20	14(17)	12 - 15	277
23	45	36	14	14(10)	12 - 14	191
24	42	31	6	14(6)	14	84
25	31	50	20	14(15)	2 - 14	258
Total and Average	39.0	50.1	15.6	14(9.04)	7.6 - 14.6	195.2

* No. of batches in brackets

APPENDIX VI. Fecundity and Longevity of E. integriceps at 28.5°C and 75% R.H; food-green wheat shoots.

Pairs No. (Replicates)	Longevity in days		No. of eggs per female			
	Male	Female	No. of batches	Usual No. of eggs per batch	Limits No. of eggs per batch	Total No. of eggs
1	42	66	20	14(14)*	10 - 14	267
2	39	49	13	14(11)	12 - 14	178
3	30	42	6	14(6)	14	84
4	36	41	11	14(8)	10 - 14	146
5	32	35	11	14(9)	10 - 14	148
6	31	34	9	14(9)	14	126
7	32	36	6	14(6)	14	84
8	30	35	7	14(7)	14	98
9	32	34	9	14(9)	14	126
10	40	43	14	14(12)	12 - 14	193
11	33	40	15	14(12)	7 - 15	202
12	32	15	2	14(2)	14	28
13	37	40	11	14(6)	7 - 22	147
14	28	38	13	14(13)	14	182
15	26	35	18	14(17)	12 - 14	250
16	18	23	3	14(3)	14	42
17	28	35	9	14(8)	10 - 14	122
18	34	40	6	14(4)	7 - 14	73
19	29	26	3	14(3)	14	42
20	34	32	11	14(11)	14	154
21	17	16	11	14(9)	12 - 28	151
22	13	19	4	14(3)	1 - 14	52
23	11	17	3	14(1)	7 - 19	36
24	12	18	7	14(6)	5 - 14	89
25	8	17	6	14(5)	10 - 14	80
Total and Average	28.1	33.0	9.1	14(7.7)	10.8-15.1	124

* No. of batches in brackets.

APPENDIX VII. Fecundity and Longevity of E. integriceps at 20°C and 75% R.H; food-barley grain and water.

Pairs No. (Replicates)	Longevity in days		No. of eggs per female			
	Male	Female	No. of batches	Usual No. of eggs per batch	Limits No. of eggs per batch	Total No. of eggs
1	27	109	0	0	0	0
2	69	77	1	9	9	9
3	103	109	2	3,6	3 - 6	9
4	23	139	3	1,8,12	1 - 12	21
5	102	62	2	5,17	5 - 17	22
6	77	59	3	17,21,24	17 - 24	62
7	50	118	0	0	0	0
8	77	44	2	14(2)*	14	28
9	68	71	6	14(2)	6 - 14	61
10	51	30	0	0	0	0
11	77	68	7	14(2)	14 - 21	117
12	15	18	0	0	0	0
13	58	64	2	13,15	13 - 15	28
14	67	56	6	13(2)	1 - 17	64
15	41	18	0	0	0	0
16	53	30	0	0	0	0
17	131	91	0	0	0	0
18	12	38	2	7,8	7 - 8	15
19	62	108	9	25(2)	3 - 26	104
20	18	23	0	0	0	0
Total and Average	59.0	66.6	2.25	Much variability 1 - 25; 14 being the commonest batch	4.65 - 9.15	27

* No. of batches in brackets.

APPENDIX VIII. Fecundity and Longevity of E. integriceps at 28.5°C and 75% R.H; food-barley grain and water.

Pairs No. (Replicates)	Longevity in days		No. of eggs per female			
	Male	Female	No. of batches	Usual No. of eggs per batch	Limits No. of eggs per batch	Total No. of eggs
1	38	42	11	14(9)*	13 - 14	152
2	12	38	11	14(2)	4 - 14	92
3	30	35	11	14(5)	2 - 17	130
4	12	24	1	14(1)	14	14
5	17	28	10	14(8)	12 - 16	140
6	13	26	4	14(2)	9 - 16	53
7	14	40	15	14(14)	14 - 15	211
8	26	28	9	14(6)	8 - 14	118
9	23	26	10	14(10)	14	140
10	40	83	19	14(11)	7 - 18	258
11	39	45	26	14(19)	7 - 14	343
12	42	52	23	14(10)	2 - 16	304
13	44	31	4	14(3)	7 - 14	49
14	51	45	20	14(5)	3 - 14	188
15	12	21	7	14(6)	2 - 14	86
16	40	59	7	14(4)	3 - 15	79
17	30	37	3	14(3)	14	42
18	32	30	9	14(7)	13 - 16	127
19	78	65	36	14(8)	2 - 15	299
20	29	42	22	14(18)	12 - 15	305
21	5	41	20	14(16)	2 - 21	266
22	23	25	18	14(16)	3 - 21	277
23	9	17	11	14(10)	7 - 16	163
24	12	42	25	14(18)	14 - 28	364
25	9	45	28	14(24)	5 - 28	377
Total and Average	27.2	38.6	14.4	14(9.4)	7.7-16.5	183.0

* No. of batches in brackets.

APPENDIX IX. Fecundity and Longevity of E. integriceps at 28.5°C and 75% R.H; food-green barley shoots.

Pairs No. (Replicates)	Longevity in days		No. of eggs per female			
	Male	Female	No. of batches	Usual No. of eggs per batch	Limits No. of eggs per batch	Total No. of eggs
1	30	43	5	14(5)*	14	70
2	48	52	7	14(5)	12 - 14	94
3	37	44	12	14(12)	12 - 14	168
4	34	43	8	14(8)	14	112
5	28	30	7	14(6)	12 - 14	96
6	36	52	12	14(11)	12 - 14	166
7	29	68	17	14(8)	2 - 14	176
8	27	53	5	14(4)	8 - 14	64
9	43	40	3	14(2)	12 - 14	40
10	30	26	0	0	0	0
11	28	26	1	14(1)	14	14
12	37	51	6	12(3)	12 - 14	77
13	33	43	4	14(3)	12 - 14	54
14	22	38	7	14(7)	14	98
15	33	30	6	14(6)	14	84
16	52	46	6	14(5)	7 - 14	77
17	33	37	7	14(6)	10 - 14	94
18	9	29	2	14(1)	12 - 14	26
19	33	37	6	14(5)	12 - 14	82
20	35	52	4	14(3)	12 - 14	54
21	18	19	8	14(3)	7 - 24	103
22	17	18	9	14(9)	14	126
23	11	12	1	18(1)	18	18
24	24	24	13	10(5)	5 - 14	130
25	23	19	5	14(3)	7 - 14	56
Total and Average	30.0	37.2	6.4	14(4.5)	10.7- 14	83.1

* No. of batches in brackets.

APPENDIX X. Fecundity and Longevity of *E. integriceps* at 28.5°C and 75% R.H; food-barley grain and water. Single mating.

Females No. (Replicates)	Longevity in days	No. of eggs per female			
		No. of batches	Usual No. of eggs per batch	Limits No. of eggs per batch	Total No. of eggs
1	58	21	14(12)*	2 - 17	275
2	28	11	14(8)	6 - 14	139
3	61	18	14(11)	6 - 14	217
4	77	2	14(2)	14	28
5	57	15	14(9)	10 - 15	202
6	76	14	14(8)	6 - 15	17[illegible]
7	87	21	14(14)	3 - 14	261
8	60	23	14(15)	5 - 16	301
9	41	22	14(14)	8 - 22	296
10	65	22	14(13)	7 - 14	289
11	39	11	14(5)	7 - 14	127
12	25	13	14(5)	9 - 14	168
13	43	6	14(3)	12 - 14	80
14	31	12	14(10)	3 - 14	155
15	46	10	12(4)	10 - 14	121
16	61	19	14(9)	10 - 14	250
17	20	4	14(3)	11 - 14	50
18	72	21	14(12)	5 - 18	256
19	39	13	14(10)	10 - 14	176
20	30	3	14(2)	13 - 14	41
Total and Average	50.8	14.0	14(8.2)	7.8 - 14.9	180.3

* No. of batches in brackets.

APPENDIX XI

Fecundity and Longevity of crowded E. integriceps at 28.5°C and 75% R.H; food- wheat grain and water. Level of Crowding: 5 pairs in each replicate

No. of Replicates	Mean Longevity in days		Mean No. of eggs per 5 females				No. of eggs per female	
	Male	Female	No. of batches	Usual No. of eggs per batch	Limits No. of eggs per batch	Total No. of eggs	No. of batches	No. of eggs
1	24.8	51.0	65	14(41)*	5 - 14	809	13	161.8
2	14.8	35.6	50	14(37)	7 - 14	658	10	131.6
3	30.6	43.0	51	14(42)	4 - 14	660	10.2	132.0
4	29.8	33.2	58	14(45)	5 - 14	749	11.6	149.8
5	39.0	46.8	75	14(61)	7 - 15	1000	15	200.0
Total and Average	27.8	41.9	59.8	14(45.2)	5.6-14.2	775.2	11.9	155.0

APPENDIX XII.

Fecundity and Longevity of crowded E. integriceps at 28.5°C and 75% R.H; food barley grain and water. Level of Crowding : 10 pairs in each replicate

No. of Replicates	Mean Longevity in days		Mean No. of eggs per 10 females				No. of eggs per female	
	Male	Female	No. of batches	Usual No. of eggs per batch	Limits No. of eggs per batch	Total No. of eggs	No. of batches	No. of eggs
1	25.1	37.1	95	14(64)*	2 - 19	1213	9.5	121.3
2	27.4	39.0	41	14(88)	7 - 14	1446	4.1	144.6
3	22.5	36.5	106	14(78)	5 - 14	1361	10.6	136.1
4	22.2	30.3	78	14(62)	7 - 14	1041	7.8	104.1
5	29.0	34.9	106	14(84)	1 - 16	1341	10.6	134.1
6	33.9	30.0	84	14(66)	6 - 14	1090	8.4	109.0
7	31.4	29.4	86	14(77)	7 - 14	1164	8.6	116.4
8	24.1	33.8	58	14(51)	7 - 14	780	5.8	78.0
9	24.2	28.4	54	14(42)	6 - 14	726	5.4	72.6
10	25.3	26.8	79	14(73)	7 - 14	1079	7.9	107.9
Total and Average	26.5	32.6	78.7	14(68.5)	5.5- 14.7	1124.1	7.8	112.4

* No. of batches in brackets.

APPENDIX XIII

Fecundity, Longevity and Distribution of Oviposition sites of *Piezodorus lituratus* in the field, fed on broom in 1965

Pairs (No. of replicates)	Longevity in days		No. of eggs laid by each female		Oviposition sites				Mean air temp. °C
	Male	Female	No. of batches	Total eggs	Leaves	Muslin	Pods	Twigs	
1	48	92	10	150	16	50	22	62	13.9
2	49	128	19	262	21	33	28	180	13.3
3	42	49	5	73	0	0	0	73	12.8
4	35	38	3	57	0	0	0	57	12.6
5	45	131	13	170	0	93	50	27	13.2
6	35	68	12	178	10	106	0	62	13.2
7	41	164	22	348	17	26	181	124	10.9
8	26	126	8	146	21	38	18	69	13.1
9	38	108	10	127	58	13	9	47	13.7
10	41	102	4	42	0	19	0	23	13.9
11	125	131	19	259	39	159	47	14	13.2
12	110	134	13	176	27	21	109	19	13.1
13	50	63	6	106	54	0	0	52	13.0
14	131	102	8	96	27	69	0	0	13.9
15	66	62	2	38	14	0	0	24	13.0
Total and Average	58.8	99.8	10.26	148.5	20.3	41.8	30.9	55.5	13.1

APPENDIX XIV

Fecundity, Longevity and Distribution of Oviposition sites of Piezodorus lituratus in the field, fed on gorsa in 1965

Pairs (No. of replicates)	Longevity in days		No. of eggs laid by each female		Oviposition sites				Mean air temp. °C
	Male	Female	No. of batches	Total eggs	Leaves	Muslin	Sepal	Spine	
1	29	38	6	76	28	20	28	0	12.6
2	26	21	2	31	0	0	0	31	12.1
3	18	36	2	42	0	30	12	0	12.4
4	38	41	2	35	0	14	21	0	12.7
5	32	42	2	26	16	0	10	0	12.7
Total and Average	28.6	35.6	2.8	42	8.8	12.8	14.2	6.2	12.5

APPENDIX XIVa

Fecundity, Longevity of Crowded P. lituratus fed on broom at 20°C and 75% R.H. Level of Crowding: 5 pairs in each replicate

Replicate No.	Longevity in days		Fecundity per five females		Mean Total No. of eggs per female
	Male	Female	No. of batches	Total eggs	
1	13.4	20.0	9	124	24.8
2	12.2	16.2	7	118	23.6
3	15.2	20.8	6	92	18.4
4	12.6	16.6	8	146	29.2
5	14.0	16.6	7	119	23.8
6	12.2	16.2	4	110	22.0
Total and Average	13.25	17.7	6.8	118.1	19.68

APPENDIX XV

Fecundity, Longevity and Distribution of Oviposition sites of *P. lituratus* fed on broom at 20°C and 75% R.H.

Pairs (No. of replicates)	Longevity in days		No. of eggs laid by each female		Oviposition sites	
	Male	Female	No. of batches	Total eggs	Pods	Muslin
1	41	46	2	50	0	50
2	58	37	1	14	0	14
3	48	37	2	42	0	42
4	47	16	1	20	0	20
5	30	56	6	83	0	83
6	34	40	2	35	29	6
7	32	28	1	27	0	27
8	32	63	2	22	0	22
9	56	33	2	42	0	42
10	27	64	6	56	6	50
11	48	45	3	61	0	61
12	50	66	4	109	0	109
13	41	30	2	37	0	37
14	63	48	2	39	0	39
15	24	41	1	28	1	28
16	19	31	3	61	14	47
17	9	12	2	31	0	31
18	10	14	2	41	10	31
19	17	22	2	45	0	45
20	21	27	3	55	0	55
Total and Average	35.3	37.8	2.45	44.9	3	41.95

APPENDIX XVI

Fecundity, Longevity and Distribution of Oviposition sites of *P. lituratus* fed on broom at 28°C and 75% R.H.

Pairs (No. of replic-ates)	Longevity in days		No. of eggs laid by each female		Oviposition sites	
	Male	Female	No. of batches	Total eggs	Leaves and Plastic	Muslin
1	18	32	2	35	0	35
2	28	34	2	30	0	30
3	25	26	2	25	0	25
4	6	31	4	57	0	57
5	7	23	2	30	0	30
6	31	30	1	20	0	20
7	8	10	1	28	0	28
8	33	35	2	36	0	36
9	8	37	8	82	27(P)	55
10	20	35	2	32	0	32
11	28	36	2	41	0	41
12	24	39	2	47	0	47
13	6	26	2	27	0	27
14	29	35	1	27	0	27
15	18	18	1	27	0	27
16	29	34	3	55	0	55
17	20	34	1	30	0	30
18	23	31	4	51	17(L)	34
19	20	39	5	58	0	58
20	29	23	3	36	0	36
Total and Average	20.5	30.4	2.5	38.7	2.2	36.5

APPENDIX XVII

Fecundity, Longevity and Reproductive Behaviour of Picromerus bidens in the field in 1964

Pairs No. (Replicates)	Mean temp °C *	Longevity in days		Pre-oviposition period	Oviposition period	Post-oviposition period	Total fecundity	No. of egg batches	No. of copulations observed
		Male	Female						
1	12.4	93	85	24	47	14	220	9	5
2	12.2	97	92	32	41	19	207	7	4
3	14.0	73	86	58	1	27	3	1	5
4	12.1	83	122	23	71	28	239	9	2
5	11.5	93	81	58	18	5	125	4	3
6	12.4	79	82	47	19	16	71	5	2
7	14.2	58	115	37	20	58	78	3	2
8	14.2	87	84	**	**	**	0	0	6
9	14.2	82	84	37	1	46	8	1	6
10	12.3	90	100	37	36	27	143	7	3
11	12.6	99	90	30	56	4	71	4	4
12	13.2	71	90	33	31	26	128	5	2
13	13.1	90	76	23	48	5	188	9	2
14	12.6	70	101	33	34	34	127	5	1
15	12.5	90	133	30	44	59	107	7	6
16	13.1	77	89	23	48	18	193	8	1
17	12.8	83	92	33	38	21	167	5	2
18	12.9	86	91	23	44	24	105	5	5
19	13.1	81	91	17	50	24	245	10	6
20	13.6	87	90	39	25	26	158	6	2
Average of 19	13.63	-	-	33.52	35.36	25.31	-	-	-
Average of 20	-	83.45	93.7	-	-	-	129.15	5.50	3.45

* Mean temperature throughout the life of females.

** No eggs laid by this female.

APPENDIX XVIII

The Average daily Temperature during the Life of *Picromerus bidens* in the Field in 1964

No. of pairs (Replicates)	Male days °C	Female days °C		
		Pre-oviposition period	Oviposition period	Post-oviposition period
1	14.5	14.4	14.6	8.3
2	14.5	16.5	13.0	7.2
3	14.0	15.2	15.8	11.2
4	13.1	17.2	10.7	8.6
5	13.7	17.2	11.6	5.7
6	13.6	16.9	13.3	7.0
7	16.0	16.5	15.4	10.7
8	10.9	*	*	*
9	11.7	17.5	13.0	12.1
10	13.1	17.5	12.7	6.8
11	13.3	16.6	14.2	7.1
12	14.0	16.9	13.5	9.3
13	13.1	17.2	13.0	9.3
14	14.3	16.9	13.8	7.3
15	12.4	16.5	14.2	6.9
16	14.3	17.2	13.0	9.3
17	11.2	16.9	13.0	8.5
18	10.9	17.2	13.8	7.9
19	11.7	17.5	14.1	7.9
20	14.0	16.8	14.7	9.3
Average	13.2	16.7	13.5	8.4
Limits	10.9-16.0	14.4-17.5	10.7-15.8	5.7-12.1

* No eggs laid by this female.

APPENDIX XIX

Fecundity, Longevity and Reproductive Behaviour of *Picromerus bidens* at 20°C and 75% R.H. Food - *Tenebrio* and *Plodia* larvae and water.

Pairs (No. of replicates)	Longevity in days		Fecundity per female			No. of copulations
	Male	Female	No. of batches	Limits of No. eggs in batches	Total No. of eggs per o	
1	146	189	14	7 - 42	339	11
2	75	97	6	18 - 52	172	9
3	21	222	7	20 - 46	238	1
4	129	135	16	3 - 37	407	12
5	117	126	8	4 - 35	134	10
6	102	116	13	7 - 28	217	8
7	72	157	13	5 - 43	331	9
8	130	163	9	25 - 53	310	11
9	66	47	2	34 - 37	71	1
10	79	134	1	36	36	7
11	57	86	8	2 - 42	97	5
12	40	73	9	14 - 39	245	2
13	65	153	10	10 - 47	250	2
14	156	152	12	5 - 52	305	4
15	165	70	7	21 - 49	214	4
16	35	120	8	9 - 50	206	2
17	56	190	10	4 - 56	258	1
18	120	92	7	11 - 39	143	2
19	63	69	8	15 - 53	224	3
20	168	58	4	24 - 42	144	4
Total and Average	93.1	122.45	8.6	13.7-43.9	217.0	5.4

APPENDIX XX

Fecundity, Longevity and Reproductive Behaviour of *Picromerus bidens* at 23.5°C and 75% R.H. Food - *Tenebrio molitor*, *Plodia interpunctella* larvae and water

Pairs (No. of replicates)	Longevity in days		Fecundity per female			No. of copulations
	Male	Female	No. of batches	Limits of No. eggs in batches	Total No. of eggs per o	
1	57	81	15	3 - 41	296	3
2	82	83	15	13 - 39	369	4
3	99	163	12	1 - 37	106	1
4	137	95	13	1 - 33	170	3
5	86	132	17	4 - 28	220	3
6	91	142	11	2 - 48	248	4
7	67	40	3	5 - 22	43	3
8	99	51	10	5 - 46	277	4
9	67	72	8	26 - 49	254	3
10	101	98	15	1 - 34	243	3
11	113	39	6	11 - 37	155	2
12	114	40	7	13 - 43	147	2
13	76	62	6	5 - 35	137	1
14	123	88	13	4 - 47	287	7
15	121	117	24	4 - 53	497	8
16	81	74	8	3 - 37	141	4
17	39	135	12	5 - 61	388	2
18	112	107	20	2 - 43	404	2
19	71	101	18	9 - 37	428	4
20	64	94	18	2 - 31	331	3
Total and Average	90.0	90.7	12.55	5.9 - 40.0	257.0	3.3

APPENDIX XXI

Fecundity, Longevity and Reproductive Behaviour of *Picromerus bidens* at 28.5°C and 75% R.H. Food - *Tenebrio molitor*, *Plodia interpunctella* and water

Pairs (No. of replicates)	Longevity in days		Fecundity per female			No. of Copulations
	Male	Female	No. of batches	Limits of No. of eggs in batches	Total No. of eggs per ♀	
1	35	43	0	0	0	1
2	53	71	10	6 - 51	184	3
3	61	58	0	0	0	1
4	47	63	2	11 - 51	62	2
5	109	97	16	2 - 28	188	9
6	65	59	4	6 - 11	33	1
7	122	48	8	2 - 29	136	1
8	76	74	9	2 - 30	89	3
9	61	123	7	3 - 20	81	0
10	101	83	19	1 - 42	314	3
11	112	98	4	4 - 9	26	0
12	79	86	4	5 - 61	98	1
13	42	43	8	5 - 36	210	3
14	72	129	12	2 - 44	183	3
15	64	46	1	6	6	6
16	80	73	13	2 - 24	134	1
17	64	85	8	2 - 35	133	4
18	36	65	6	5 - 35	92	2
19	59	64	7	2 - 31	98	1
20	119	47	6	12 - 29	109	7
Total and Average	72.85	72.75	7.2	3.9 - 28.6	108.8	2.6

APPENDIX XXII

Fecundity and Longevity of Virgin Picromerus bidens at 20°C and 75% R.H. Food - Tenebrio molitor, Plodia interpunctella larvae and water

No. of females	Longevity in days	Fecundity per female		
		No. of batches	Limits of No. eggs in batches	Total No. of eggs per ♀
1	133	9	4 - 24	114
2	233	10	3 - 20	96
3	239	9	3 - 27	103
4	255	9	5 - 25	105
5	261	11	1 - 37	207
6	210	5	5 - 13	54
7	223	8	1 - 32	113
8	187	8	2 - 35	128
9	132	7	5 - 17	78
10	104	4	7 - 50	89
11	120	12	1 - 31	99
Total and Average	190.6	8.3	3.3 - 28.2	107.8

APPENDIX XXIII

Fecundity, Longevity and Distribution of Oviposition Sites of Picromerus bidens (reared in the laboratory) at 20°C and 75% R.H. Food - Tenebrio molitor, Pieris brassicae larvae and water

No. of Pairs (replicates)	Longevity in days		Fecundity per female			Oviposition sites Eggs per female	
	Male	Female	No. of batches	Limits of No. eggs in batches	Total eggs per ♀	Cardboard	Muslin
1	61	87	10	8 - 39	192	192	0
2	67	102	6	1 - 55	123	123	0
3	93	74	2	16 - 28	44	28	16
4	62	46	2	21	42	0	42
5	67	103	5	15 - 40	114	114	0
Total and Average	70	82.4	5	12.2-36.6	103	91.4	11.6

APPENDIX XXIV

Fecundity, Longevity and Distribution of Oviposition Sites of *Picromerus bidens* (reared in the laboratory) at 20°C and 75% R.H.

Food - *Tenebrio molitor*, *Plodia interpunctella*

Level of Crowding: 5 pairs in each replicate

No. of replicates	Mean Longevity in days		Fecundity per 5 females		Total No. of eggs per female	Oviposition sites Eggs per 5 females		
	Male	Female	No. of egg batches	No. of eggs		Cardboard	Muslin	Plastic
1	42.8	40.4	32	1108	221.6	804	186	118
2	40.2	43.6	26	882	176.4	770	89	23
3	35.6	39.4	24	844	168.8	654	134	56
4	48.2	50.8	42	1494	298.8	1262	210	22
5	65.0	69.2	48	1280	256.0	1099	144	37
Total and Average	46.3	48.6	34.4	1121	224.3	917.8	152.6	51.2