THE NYMPHAL AND IMAGINAL STAGES OF THE BISEXUAL STICK INSECT CLITARCHUS HOOKERI (PHASMIDAE : PHASMINAE)

I. A. N. STRINGER,
Zoology Department, University of Auckland.

The following observations were made on the instars of **Clitarchus hookeri** (White) (Phasmidae, Phasminae) while rearing a small number of both sexes for dissection purposes.

No descriptions of the instars of **C. hookeri** have been found and only Salmon (1955) implied that there are four moults. During the present study seven instars (i.e. six moults) were observed in both sexes. Twenty newly hatched insects were reared but as only two adults emerged morphological characters were studied. The classification followed is that of Günther (1953).

METHODS

Adults stick insects were collected from manuka scrub at Bethells Beach, Auckland, and kept in a large cage supplied with fresh manuka every two or three days. Most of the nymphs were reared from eggs and kept on small potted manuka in a glasshouse. Two nymphs of each sex were collected when half grown from Bethells Beach and also were observed.

Eggs were collected from the floor of the adults' cage and kept at room temperature on a grooved plastic foam tray enclosed within a clear plastic box. Water on the floor of the plastic box maintained a high humidity, and mould was controlled, when it occurred, by spraying with a 1% solution of nipagin-M-sodium.

A separate bush was used for each instar, nymphs of the same instar being kept together on the same bush. Each time an insect moulted it was transferred to the appropriate bush. The bushes with adults and last nymphal stages were enclosed within cages as they had a tendency to migrate. First and second instars required water which was supplied every morning as fine droplets sprayed onto the bushes.

The stick insects usually ate their exuviae (except at the first moult) and therefore the total body length was measured every one or two days so that changes could be noted and parts of exuviae could be found to confirm ecdysis (always small parts, such as legs, were not eaten). Individual insects older than first instar could be identified by physical characters such as missing legs, colour and/or arrangements of spines, and their progress followed.

Care had to be exercised in handling the nymphs during measurement or they would regurgitate fluid or lose a leg. The insects were sandwiched between two clear disposable plastic petri dishes and their lengths measured with graph paper placed underneath. The upper petri dish stood on small rounded knobs which protected the smaller nymphs and it fitted into the lower petri dish so that parallex errors were reduced.

The insects were observed during the winter of 1968 with the temperature inside the thermostatically heated glasshouse at 70°± 10°F. Measurements were discontinued in October due to the obviously abnormal condition of the remaining insects; they became thin overnight, fluid dried around their anal apertures and mouthparts, and they usually died within two days. However, one male and two females successfully reached imagines.

All drawings were taken from recently killed insects with the aid of a squared graticule in a binocular microscope.

RESULTS

Both sexes of **C. hookeri** were observed to undergo six moults, there being six nymphal instars and the imaginal stage.

The observed differences between the stages are summarised at the end of this section in the form of a key. Useful characters included the number of antennal annuli, the female external genitalia and to a lesser extent the male genitalia, and (for first and second instars) the total body length and degree of fusion of the first abdominal segment with the metathorax.

1. The instars can be recognised by the number of annuli in the antennal flagellum although this is of limited accuracy since parts of it are often lost at ecdysis (as are occasionally the legs) and this accounts for specimens collected in the field sometimes having unequal antennae.

The antenna of the newly hatched insect has a flagellum with seven annuli, a scape, and a pedicel. The annuli divide during growth except for the distal member and the scape and pedicel. At the first moult the meriston (Henson, 1947) or proximal annulus becomes internally divided into three and each of the second to sixth annuli internally divided into two. Towards the end of the second instar two additional divisions occur within the meriston and at the second ecdysis all these become full annuli so that there are now sixteen. The ninth, eleventh, thirteenth and fifteenth annuli are slightly larger and darker than the annuli immediately preceding them, and these annuli can often still be recognised in the fifth and sixth instars. At subsequent moults additional annuli are proliferated only at the meriston; two additional annuli appear at both the third and fourth moults, and one or two at the fifth and sixth moults. Just before each ecdysis internal divisions become apparent in the meriston where the new annuli will form. Thus there are distinct differences in the number of annuli in all but the last nymph and adult.

The antennae form the best guide to the different male stages since the male genitalia do not change much during the ecdyses. However, the female instars are best characterised by their genitalia.

2. The adult male genitalia (fig. 1A) are close to the typical Phasmid structure described by Snodgrass (1937). They comprise a genital bulge formed by the eighth and ninth sterna together with toothed claspers which curve around behind the cerci from the posterior ventral edge of the tenth tergum. The ninth sternum is divided by a flexible joint into an anterior sternite and a posterior hypandrium. The hypandrium forms a cover for the withdrawn

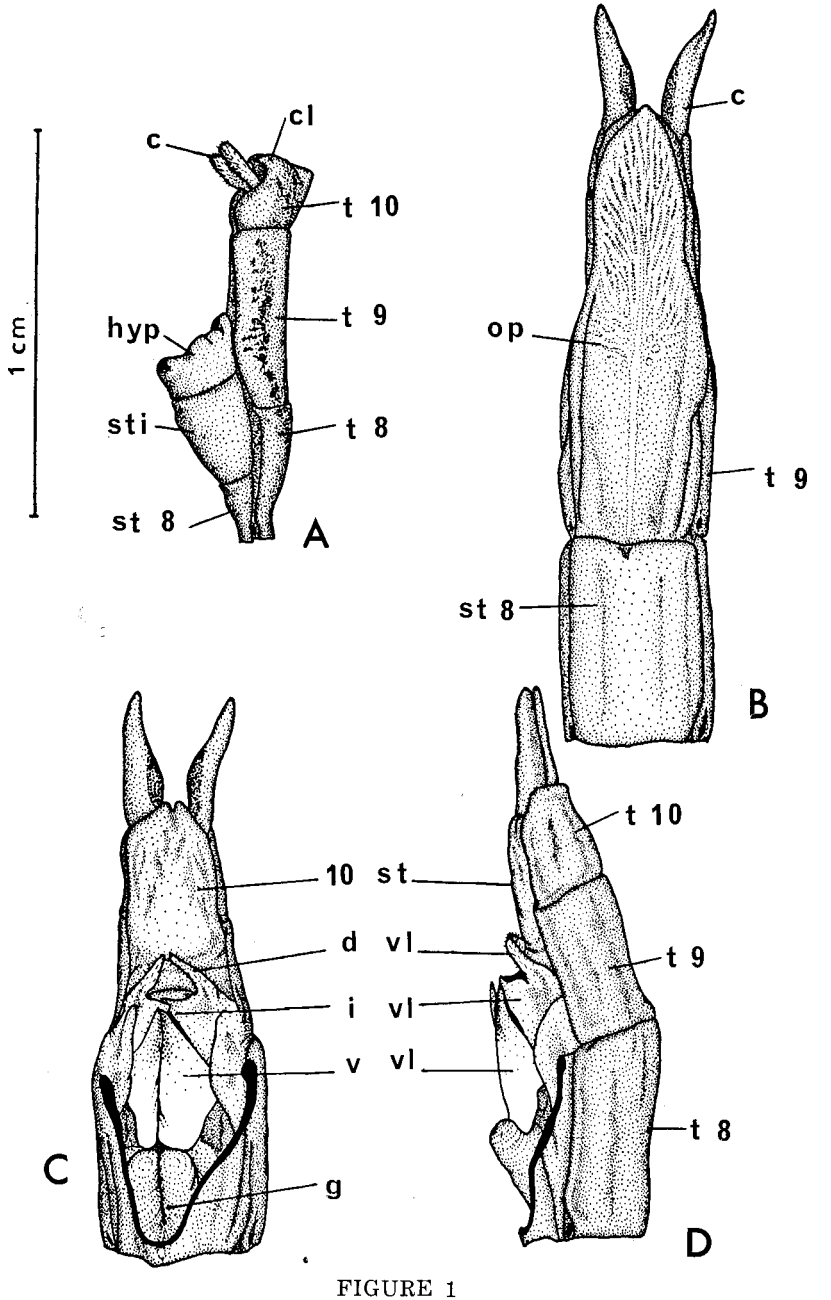

FIGURE 1
TERMINAL ABDOMINAL SEGMENTS OF ADULT **C. hookeri**

A. Male, lateral aspect.
B. Female, ventral aspect.
C. Female, ventral aspect; operculum removed.
D. Female, lateral aspect; operculum removed.

c, cerci; cl, claspers; d vl, dorsal valvulae; g, genital opening; hyp, hypandrium; i vl, inner valvulae; op, operculum; st, sternum; t, tergum; v vl, ventral valvulae.

phallus (bearing the genital aperture) which is protruded from beneath the posterior lip when the hypandrium is raised. The ninth tergum is elongated beyond the genital bulge (with a pleural area ventrally) while there is a distinct tenth sternum but no subanal vomer.

The adult female genitalia are typically orthopteran (Snodgrass, 1933). The eighth sternum forms a large operculum (subgenital plate) which covers the genitalia and most of the tenth sturnum (fig. 1B). The reduced ovipositor consists of a pair of ventral valvulae arising from the eighth segment behind the base of the operculum and paired dorsal and inner valvulae arising from the ninth sternum (fig. 1C and D). The ventral and inner valvulae are both soft and flexible and together enclose an egg chamber. The genital aperture lies ventrally between two membranous genital lobes at the base of the operculum and is separated from the ventral valvulae by the opening to the bursa copulatrix.

First instar male and female nymphs can readily be distinguished; the male has a slight mounding of the ninth sternum which terminates in a fold towards the posterior of that segment (fig. 2A, A'), while the female has a distinct transverse fold in the middle of the eighth sternum and paired tubercles at the posterior of sterna eight and nine which are often pigmented red (fig. 3A, A').

In the male the changes in the genitalia are slight (fig. 2), although the degree of development of the claspers, relative length of the eighth, ninth and ten tergites, position of the genital bulge with respect to the eighth and ninth tergites, and subdivision of the ninth sternum are of some value in distinguishing the instars.

In the female the main criteria for distinguishing the instars are the length of the operculum relative to the eighth, ninth and tenth tergites together with the degree of development of the ovipositer (fig. 3).

3. Total body length was useful in distinguishing first and second instars. First instars grow in length from approximately 1.1 cm to 1.6 cm, while the lengths of older instars remain relatively constant. There is a distinct increase in length at each ecdysis, the change at the first moult being relatively quite large (from ca. 1.6 cm to ca. 1.9 cm) and characteristic. A similar gap (max. 1.65 cm to min. 1.8 cm) was also found in the field. The body lengths of other instars overlapped so that body length would not be a good criterion for distinguishing these stages.

Other changes noted were as follows: Many insects did not develop notal tubercles, but in those that did, these appeared at any moult after the third. There were no leg spines on first instars, and only disto-lateral femoral projections on second instars. Other spines appeared at subsequent ecdyses in variable numbers. In first instar nympths the first abdominal segment was distinct from the

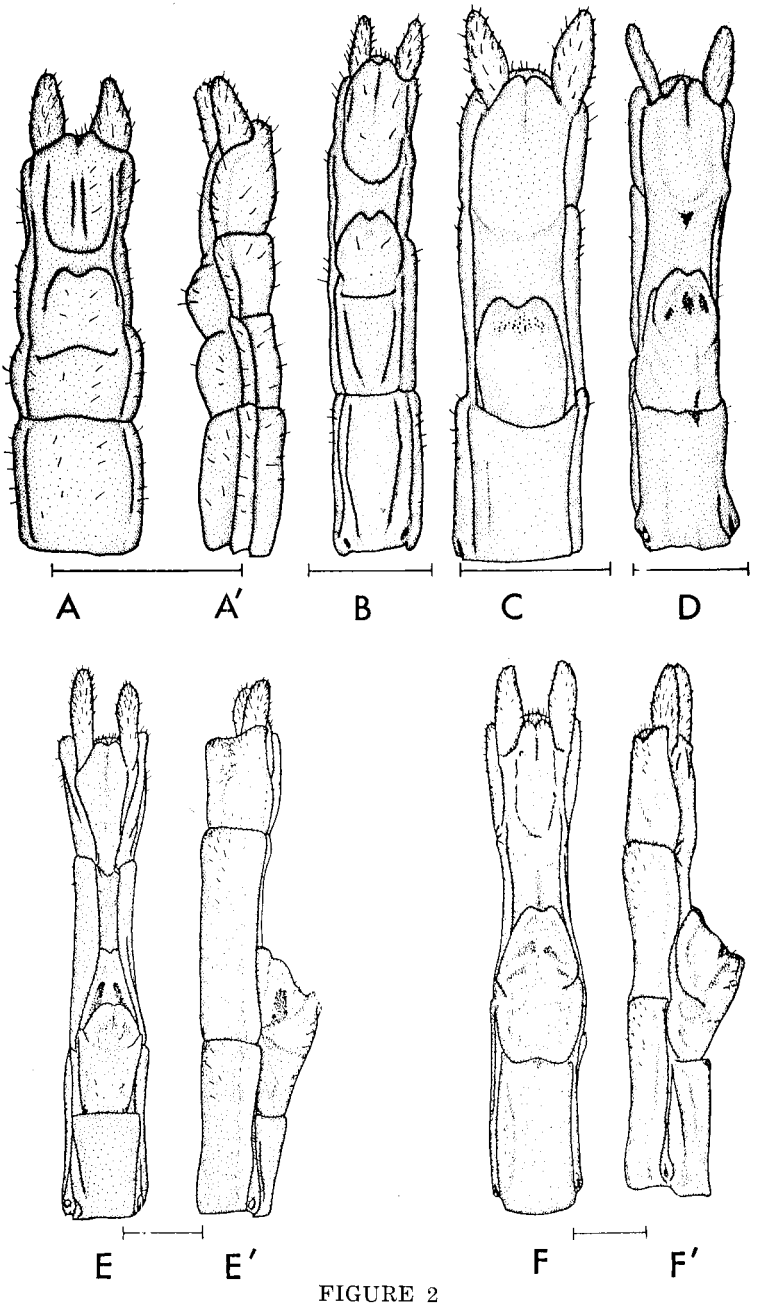

FIGURE 2

TERMINAL ABDOMINAL SEGMENTS OF IMMATURE MALE **C. hookeri**

A. 1st Instar.
B. 2nd instar.
C. 3rd instar.
D. 4th instar.
E. 5th instar.
F. 6th instar.

A', E', F', lateral aspects of corresponding instars.

Scale 1 mm.

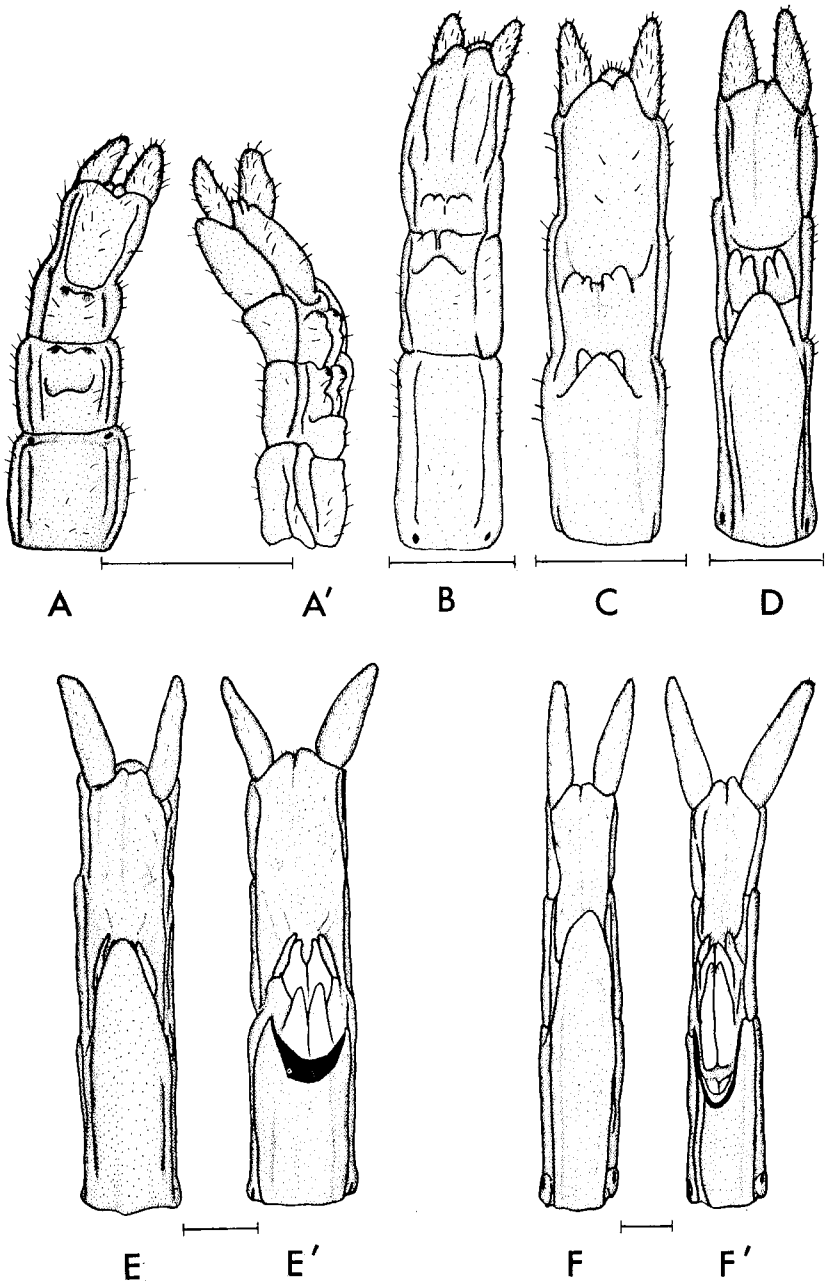

FIGURE 3
TERMINAL ABDOMINAL SEGMENTS OF IMMATURE FEMALE **C. hookeri**

A,A'. 1st instar, ventral and lateral respectively.
B. 2nd instar.
C. 3rd Instar.
D. 4th instar.
E. 5th instar.
F. 6th instar.
E', F', Operculum removed from corresponding instars.
Scale 1 mm.

metathoracic notum and the junction was only partly obliterated in second instars. In all later instars the metathoracic and first abdominal terga were fused and the position of the junction was marked only by slight indentations on either side of the tergum. First instar nymphs always hatched green, and colour change occured at any time from the end of the first stadium to the fifth stadium, and took a period of one or two stadia to complete. The body and prothoracic legs turned brown first followed by the meso- and metathoracic legs. The bright red colouration of the adult female stick insects on the proximal region under the antennae and on the ventro-basal portions of the femora first became noticeable during the fifth instar and prominent in the sixth instar and adult.

KEY TO THE INSTARS OF **C. hookeri.**

1—(a) First abdominal tergum distinct 2
(b) First abdominal tergum completely fused with metathorax 3

2—(a) Body less 1.7 cm long. Seven annuli in flagellum. First abdominal and metathoracic tergum distinct. First abdominal tergum as long as second tergum. No spines on legs.
FEMALE. Operculum a small median fold on segment 8. Small pair of posterior tubercles each on segments 8 and 9 . . . . . 1st Instar

(b) Body greater than 1.8 cm long. Seven annuli in flagellum; all but distal one with internal divisions. Junction of metathoracic notum and first abdominal tergum incomplete; latter 2/3rds length of 2nd abdominal tergum. Disto-lateral femoral projections present.
FEMALE. Operculum a small lip reaching groove between ventral valvulae. Dorsal and inner valvulae as separate but slight tubercles . . 2nd Instar

3—(a) 16 annuli in flagellum.
FEMALE. Operculum covers base of ventral valvulae. Dorsal and inner valvulae distinct flaps. . . . . 3rd Instar

(b) 18 annuli in flagellum.
FEMALE. Operculum completely covers ventral valvulae and reaches base of dorsal and inner valvulae . . . . . 4th Instar

(c) 20 annuli in flagellum.
FEMALE. Operculum covers internal valvulae, dorsal valvulae project only slightly around edge. Red coloration appearing . . . . 5th Instar

(d) 21 or 22 annuli in flagellum.
FEMALE. Operculum covers valvulae. Red prominent.
MALE. No teeth on claspers, which are prominent bulges at posterior edge of 10th tergum.
. . . . . 6th Instar

(e) 22 to 24 annuli in flagellum.
FEMALE. Operculum reaches almost to tip of abdomen; V shaped in cross section. Abdomen thicker than thorax when gravid.
MALE. Claspers toothed. Abdomen always as thick as thorax . . . . . Adult

DISCUSSION

The observed number of seven stadia in **C. hookeri** cannot be taken as representative of the population because of the small number of later instars studied. This number, however, is probable because the total body length of the reared adults fell within the range observed at Bethells Beach (Stringer, 1968) and Phasmids reared by other workers do not show variations in the number of moults. However, the first three instars (from 10 observations each) and the fourth instar (from 8 observations) are certain. Sixth female nymphal instars can be recognised in the field but as there is no sharp distinction between fifth and sixth instar nymphs, the possibility exists that there may only be five nymphal instars. There may be only five male nymphal moults at Bethells Beach as the male instars also cannot be distinguished clearly. Thus, it can only be said with certainty that there is a minimum of six and a maximum of seven stadia in each sex.

In the female the progressive development of the genitalia forms the easiest method of identifying the instars and this has been used by workers on other stick insects, for example Savage (1957) for **Carausius morosus,** Hadlington and Hoschke (1959) for **Ctenomorphodes tessulata,** and Gangrade (1963) for **Necroscia sparaxes.** It is interesting to note that in the Phyllidae the sexes are hard to distinguish in the first instar, and sexual differentiation is delayed; for example **Necroscia sparaxes** (Korinninae) can be sexed only after the first moult (Gangrade, 1963), while in **Timema californica** (Timeminae) Gustafson (1966) notes "As the genitalia are not fully developed until the final moult, to determine the sex of the immature instar is difficult or impossible". In the Phasminae the operculum shows as a small transverse structure as for example in **Carausius morosus** (Lonchodinae) (Savage, 1957) and **Ctenomorphodes tessulata** (Phasminae) (Hadlington and Hoschke, 1959). In these two species the development of the ovipositor is similar to that in **C. hookeri.**

In the male, the best character for identifying the instars was found to be the number of annuli in the antennae although this was not always reliable since the antennae often broke during ecdysis. Hadlington and Hoschke (1959) also found the annuli to be of use in determining the male nymphal stages of **Ctenomorphodes tessulata** although they had the added character of wing bud development.

It was found that most of the antennal growth occurred in **C. hookeri** at the meriston but the second to sixth annuli of the first instar divided during the first and second moults. In most insects the meriston is where the annuli proliferate (Imms, 1940) but in **Ctenomorphodes tessulata** there is a doubling of the annuli at the third moult which suggests division of more than the meriston (Hadlington and Hoschke, 1959). Ling Roth (1916) found that all the annuli of **Carausius morosus** divided, while reference to the increase in the antennae of other Phasmids during growth are limited to their lengths, possibly because the annuli may be internally divided and hard to count. Imms (1940) and Uvarov (1966) also note division of the proximal annuli in Orthoptera.

The habit of stick insects eating their exuviae is well known, both in New Zealand forms (Yates 1950, Salmon 1955) and others (e.g. Talbot 1920, Gangrade 1963, Key 1957) and may have contributed to the confusion in the number of moults recorded (three to seven) in **Carausius morosus** by various authors (Savage, 1957). This may also explain the implied observation of Salmon (1955) that there are five instars in **C. hookeri.**

ACKNOWLEDGMENTS

This work was undertaken as part of an M.Sc. thesis at Auckland University and I wish to thank Professor J. G. Pendergrast and Mr. D. R. Cowley for their supervision.

REFERENCES

GANGRADE, G. A., 1963: A contribution to the biology of **Necroscia sparaxes** Westwood (Phasmida). **Indian J. Ent. 25:** 307-10.

GUNTHER, K., 1953: Ueber die taxonomische gliederung und die geographische verbreitung der insektenordung der Phasmatodea. **Beitr. Ent. 3:** 451-562.

GUSTAFSON, J. F., 1966: Biological observations on **Timema californica** (Phasmoidea: Phasmidae). **Ann. ent. Soc. Amer. 59:** 59-61.

HADLINGTON, P., and HOSCHKE, F., 1959: Observations on the ecology of the Phasmatid **Ctenomorphodes tessulata** (Gray). **Proc. Linn. Soc. N.S.W. 84:** 146-59.

HENSON, H., 1947: The growth and form of the head and antennae of the earwig **Forficula auricularia. Proc. Leeds Phil. & Lit. Soc. (Sci. sect.) 5:** 21-32.

IMMS, A. D., 1940: On growth processes in the antennae of insects. **Quart. J. micro. Sci. 81:** 585-93.

KEY, K. H. L., 1957: Kentromorphic phases in three species of Phasmatodea. **Aust. J. Zool. 5:** 247-84.

LING ROTH, H., 1916: Observations on growth and habits of the stick insect, **Carausius morosus** Br. **Trans. ent. Soc. London. 1916:** 345-86.

SALMON, J. T., 1955: Stick insects. **Tuatara 5** (3): 77-81.

SAVAGE, A. A., 1957: The identification of the nymphal and imaginal stages of the stick insect, **Carausius morosus** Brunner (Orthoptera). **Proc. Leeds Phil. & Lit. Soc. (Sci. Sect.) 4:** 29-33.

SNODGRASS, R. E., 1933: Morphology of the insect abdomen Part II. The genital ducts and the ovipositor. **Smithsonian Misc. Coll. 89** (8): 148 pp.

1937: The male genitalia of Orthopteroid insects. **Smithsonian Misc. Coll. 96** (5): 23-29.

STRINGER, I. A. N., 1968: Aspects of Reproduction and Development in **Clitarchus hookeri** White. University of Auckland, unpublished Thesis.