



Research Article

Description of copulatory complex in relation to taxonomy in Gerridae

Jagvir Singh^{1*}, Y.C. Gupta¹ and H.N. Sharma²

¹*Department of Zoology, B.S.A. College, Mathura, Uttar Pradesh 281004, India.*

²*Department of Environmental Toxicology, School of Life Sciences, Dr. B.R. Ambedkar University, Agra-282002, India.*

Abstract: The family Gerridae is represented in India by 67 species (of which 4 are undescribed species and only known by the nymphs) belonging to 20 genera and representing 7 subfamilies (10 new species are described in the present work). The subfamily Charmatometrinae is not represented in India. The Gerrids or water striders are well known aquatic insects and they are the most interesting and fascinating among all insects of the tropics and subtropics. They skate, skip, glide or literally walk upon the surface of the water. The relation of copulatory complex with taxonomy is described in this research article.

Keywords: Gerrids, Pygophore, Valvulae, Parameres, Phalotheca, Connexival spines, Suranal plate.

1. Introduction

The Gerridae differ from the members of other closely related families in having very long hind femora which extend considerably beyond the apex of the abdomen. The body is light in weight and usually slender, covered with a waterproof coat of very fine hairs. The head is elongated, pointed in front and wider at the eyes with short, slender four-segmented antennae, large eyes, ocelli present, greatly reduced rostrum with four segments, wings absent, reduced or present even in the members of the same species. The forelegs are modified to hold the prey; the mid and hind legs are very long, slender and are used in walking on the surface of the water. The tarsus is two segmented and clothed with fine hairs. Life history is very simple. They lay their eggs in water, the eggs being inserted into the plant tissues or attached to plants and other objects in gelatinous masses. Development is direct. The young hatch from submerged eggs and at once begin life on the surface. There may be one to several generations in a year. In cold, the adults hibernate under stones, logs, and other debris around the margins of the water, and in semi-arid regions.

They may even jump from the surface of the water into the air to catch small insects. They chiefly inhabit ponds, the margins of lakes, the more sluggish water and edges of rivers, streams, and oceans. The Gerrids

are predacious in habits and they prey upon such small insects etc. that fall into the water. They also feed on dead insects and other available small animals.

2. Materials and Methods

The material for the present study was collected from the various localities of Uttar Pradesh, Rajasthan, Madhya Pradesh, Himachal Pradesh, Punjab, Haryana, West Bengal, Assam, Delhi, Kashmir and South India. The Gerrids were easily recognized by their long hind femora which extend considerably beyond the apex of the abdomen and collected by using an ordinary pond net from various habitats such as ponds, margins of lakes, edges of rivers, streams, and estuaries. A few species were also procured at the light. They were killed immediately on collection in 90 percent alcohol, which was found to be a very good preservative. A large number of specimens of unnamed Gerridae, I also received from the University of Michigan, U.S.A., Rijksmuseum van Natuurlijke Historie (National Museum of Natural History) Leiden, Z.S.I. (N.R.S.) Dehradun, Z.S.I. (H.A.Z.F.S.) Solan, F.R.I. Dehradun, India Biologic: Products, Madras for the present works. The opportunity was also availed to study the national collections of Gerridae maintained at the Indian Agricultural Research Institute, New Delhi; Zoological Survey of India, Calcutta; Zoological Survey of India

*Corresponding author:
E-mail: drhnsharma2015@gmail.com.

(N.R.S.) Dehradun; Zoological Survey of India, (H.A.Z.F.S.) Solan and at F.R.I. Dehradun. The types of Gerridae available at Z.S.I. Calcutta were also studied and assessed.

After determination, most of the specimens were preserved in 90 percent alcohol and the representative specimens were pinned as usual and kept in entomological boxes. The genitalia were taken out with the help of forceps. From the dry specimens, the genitalia were similarly taken out after the insects were softened in desiccators. The genitalia were then mounted on D.P.X. after processing as usual. By the courtesy of the Director, Z.S.I., Calcutta, the genital preparation of some of the species were made, studied and deposited at Z.S.I., Calcutta.

All the drawings were made with a camera Lucida. The colour patterns were drawn from entire specimens. All the measurements were taken by using an eyepiece micrometer. Length of insects was measured from the tip of the head to the tip of the abdomen and breadths were measured across the head including the eyes, and across humeri, and across mesoacetabula; the leg segments were measured from end to end, so were the antennal segments. The small joints between the segments of the antenna were not included in the antennal segment measurements. The material collected during the present studies is in the author's possession and will be deposited in National collections at the Zoological Survey of India.

3. Results and Discussion

The research article is an attempt to elucidate the structural evolution of copulatory complex of the Gerridae of India and to establish its relation to the taxonomy. To attain these objectives the structure of copulatory complex of the species of Gerridae of India was studied in frequent comparison with other Hemiptera and other major groups of insects to establish homologies and terminology of structures.

3.1 Origin of male copulatory complex in Hemiptera

Before studying the copulatory complex of the Gerridae, it is worthwhile to mention recent opinions in regard to the origin of copulatory complex of insects with special reference to Hemiptera. The copulatory complex of insects are generally concerned to be the derivatives of segmental limbs i.e., coxal in origin. Dupuis suggested that the male copulatory complex of Insects are the derivatives of tenth abdominal limbs, and coined the term euphallic and pseudophallic organs to the phallic organs including parameres i.e. the tenth coxites and to the structure from the ninth coxites respectively, and applied his theory to Heteroptera. Snodgrass suggested that the male copulatory complex, including those of Heteroptera, is the derivatives of ninth sternum. Matsuda attempted the origin of copulatory complex in insects and supported the view

of Snodgrass. Woodland on the basis of embryological studies on *Thermobia domestica* suggested that the copulatory complex has nothing to do with the coxites in their developmental mental origin. The foregoing discussion on the development of opinions in regards to the origin of copulatory complex of insects indicates that the male copulatory complex of insects is not the derivatives of the appendages. Dupuis contribution is important in gathering the widely scattered information about the male copulatory complex of Heteroptera and provides basic concepts regarding the origin of male copulatory complex. Snodgrass & Matsuda derive the male copulatory complex from the tenth abdominal appendages which are not well founded and harbour many contradictions. In the opinion of Bonhag & Wick, the ninth sternite has given rise to the male copulatory complex. Quadri suggested on the basis of the innervations of the copulatory complex in *Dysdercus* that the tenth abdominal nerves innervate the accessory gland to the median ejaculatory duct and intromittent organ. A study of innervations is helpful in deciding the segmentation. While the sternal origin of male copulatory complex is well supported by evidence, whether they are derived from ninth or tenth segment. In the present distribution, Bonhag and Wick's finding and interpretations are followed.

3.2 The male copulatory complex of the Gerridae

The pygophore is the fusion product of the 9th coxites. It covers ventrolaterally the genital chamber and excises the invaginated phallic organs. The pygophore is dorsally fused at its base, forming a narrow sclerotized bridge. The suranal plate is usually considered to be the 10th segment or 10th tergum by morphologists, as well as by taxonomists. Bonhag and Wick, however, found this to be the 9th tergum in *Oncopeltus*. One great advantage attached to Bonhag and Wick's interpretation is that it is the 9th tergum in the male that bears apically the anus and this is the condition in the female in the Gerridae. Thus, if Bonhag and Wick are followed, the homology of the genital segments between the two sexes becomes much easier than in other theories. Bonhag and Wick's findings and their interpretations are followed in the present work and so labelled.

The male phallic organs of the Gerridae were studied by Poisson, Singh-Pruthi, Schroeder etc. Dupuis also summarized the male genitalia in various group of Heteroptera. The basal plate is attached laterally to the pygophore, sustaining the phallosome within the genital chamber. The parameres arise from the point of connection of the basal plate to the pygophore. The phallosome lies in the genital cavity with the basal end caudad and resting on and partly surrounded by the basal plate. During the copulation, the phallosome is raised and pushed backward, then down, transcribing almost a complete circle. The phallosome contains the invaginated endosoma within. The endosoma is further divided into the proximal and distal membranous

segments, and the conjunctiva, its base attached to the basal plates and communicating with the body cavity through the basal foramen. The phallosome is barrel shaped, open at the distal end, through which the endosoma is extruded. The conjunctiva joins the distal end of phallosome to the basal part of the endosoma. The distal segment of the endosoma is usually provided with three pairs of sclerotized plates. These are:

- (i) The median dorsal plate;
- (ii) The ventral plates, and
- (iii) The lateral plates.

The median dorsal plate is the fusion product of originally paired plates; the ventral plates carry the ejaculatory duct. The shape, size, and number of plates very much vary in Gerridae, due to loss and fusion of plates.

3.3 Origin of female copulatory complex in Hemiptera

Matsuda on the basis of contribution of Christopher and Cragg on the development of female copulatory complex in *Cimex* supported the view expressed by Heymons that the gonapophysis arises from the primary sternum and the valvifer is the modified sternum. Gillet on the basis of post-embryonic development of female copulatory complex in *Rhodnius* suggested that a pair of buds arise on the 8th & 9th sternites. Each pair differentiates into outer and inner pairs, the inner pair on the 8th segment during into first valvular, while the outer pair remains and forms only the first valvifers. The inner pair of buds on the 9th segment develops into second pairs of valvulae while the outer pair develops into the 3rd pair of valvulae and their bases from the second valvifers. These structures are the gonocoxites of eighth & ninth segments. The foregoing discussion makes it clear that there is no factual evidence to support the theory of appendicular origin of female copulatory complex in Heteroptera. The valvulae are the valvifers and therefore regarded as sternal striders in the present work.

3.4 The female copulatory complex of the Gerridae

The gonapophyses (Valvulae) arise from the primary sternum and the valvifer is modified sternum. Snodgrass (431) summarized the basic structural pattern of the female external genitalia of Hemiptera. According to him, the shaft of the ovipositor is formed of the first and second valvulae, the first being external and ventral, the second internal and dorsal. The second valvulae are usually united with each other, either for a part or for most of their length. The first valvifers have a plural position below the tergum on the sides of the eighth segment, through their posterior angles may be flexibly attached to the ninth tergum. The dorsal muscles of the first valvifers arise on the eighth tergum. The first valvulae have each two proximal rami. The outer ramus is flexibly attached to the ventral angle of

the first valvifer; the inner ramus is united with the anterior inner angle of the ninth tergum. The ninth tergum is exposed and often large in size and its anterior ventral angles are produced, forward as extensions to which are united the rami and first valvulae. The second valvifers have a plural position on the sides of the ninth segment beneath the lateral margins of the ninth tergum. The second valvulae are attached proximally to the anterior end of the second valvifer and the ramus slides on the concave margin of the inner ramus of the corresponding first valvula. The third valvulae are well differentiated from the second valvifers; they form a pair of lobes ensheathing the distal end of the shaft of the ovipositor; sometimes they are absent. The third valvulae and the second valvifers are often absent in Gerridae. In *Gerris adelaidis* Dohrn the first valvula is divided into inner short and outer longer lobes being directly connected with the first valvifer, which is a broad sclerite behind the seventh sternite. The vulva is situated between the inner lobes of first valvulae. The second valvulae are connected by the intervalvular membrane. The apical end of the ramus is loosely attached to the inner margin of the ramus of the first valvula due to loss of the second valvifer.

3.5 The Copulatory complex and its bearing on the taxonomy in Gerridae

The study of the copulatory complex in the species of the Gerridae of India has brought to the notice a large number of significant points to the knowledge. In primitive insects of the seventh abdominal segment is supposed to be similar in form to the preceding segment, but this primitive condition in Gerridae encountered the difficulty that no species of the Gerridae is the posterior margin of the seventh segment of the ventral surface straight as is the sixth. It is either broadly concave or curiously modified and often the seventh segment is strongly produced posterior as the connexival spines. The posterior margin is usually concave and the segment has a strong tendency to produce lateral caudally. This condition was observed in primitive species of primitive genera of Gerrinae such as *Eotrechus*, and more primitive species *Aquarius* and *Limnometra*. In these species, the second to sixth segment is long and six equal to each other and lateral projections of seventh segment are more or less conspicuous. In the primitive Gerrids, the seventh segment on its median longitudinal axis is about 2/3 to 3/4 as long as sixth segment ventrally and the posterior margin is strongly concave. From this primitive condition, the seventh segment has undergone various modifications in different species of Gerridae.

The connexival spines are not found in Eotrechinae and Charmatometrinae but are present in more primitive species of more primitive genera of Gerrinae and Cylindrostethinae. The absence of connexival spines in the more specialized genera simulates the condition in *Eotrechus*. In *Eotrechus* the abdominal segment is generalized and long, while in the species without

connexival spines in Gerrinae and Cylindrostethinae, the abdominal segment is greatly reduced. The reduction of abdominal segment reflects the progressive reduction of the connexival spine in Gerrinae and Cylindrostethinae. It is likely that connexival spine never occurred in Eotrechinae and Charmatometrinae and the absence of connexival spines in more specialized species of Gerrinae and Cylindrostethinae is the result of the secondary lost. It is thus impossible to say that the absence or presence of connexival spine is a primitive or specialized condition in the Gerridae. The evolution of the seventh segment is somewhat different in two sexes. In male Gerrinae the connexival spine occurs in *Limnometra*, *Tenagonus* (s.str.) complex and in *Cylindrostethus*. In these genera, the connexival spines gradually obliterated with the specialization of the abdominal segment. The degree of prolongation is indicated by the length of the seventh segment on the median ventral longitudinal axis. In the primitive Gerridae, the seventh segment is shorter than the sixth. The seventh segment has prolonged simultaneously with the reduction of second to sixth ventral abdominal segment. This was observed at both the specific and generic level within the subfamily Gerrinae. The greatest prolongation of the segment was observed in *Amemboa* and *Chimarrhometra*. In Charmatometrinae the ventral posterior margin of seventh segment has become emarginate in the middle. The modification of seventh segment. *Limnometra*, *Tenagonus* (s.str.) complex is peculiar. In this species, the connexival spines are progressively reduced with the specialization of the abdominal. In Ptilomerinae the seventh segment has undergone conspicuous modification in males. The same applies to Rhagodotarsinae and Halobatinae and in some genera of Gerrinae and Ptilomerinae. The connexival spines are more conspicuous in females than in males and are often retained in females when they are completely lost in the male of the same species as is observed in some species *Limnometra* and *Gerris* (s.str.). In Ptilomerinae the 7th segment has undergone drastic modification. In primitive form, such as the subgenus *Ptiomera* of the genus *Ptilomera* and *Rheumatogonus* these occur no connexival spine. The absence of connexival spine appears to be a primitive condition in the subfamily. In Rhagodotarsinae the 7th segment is simply prolonged and without connexival spines and the ventral apical margin is concave. In Halobatinae the connexival spines are absent and ventral apical margin is simply concave in all genera except for *Metrocoris* in which a lobate structure occurs on the ventral apical margin. The curious modification in the female of the ventral apical margin in some genera of Gerrinae, Ptilomerinae, and Halobatinae provides a good generic as well as specific character. The absence of this modification even in specialized genera of Rhagodotarsinae suggests a difference from other subfamilies. Since the female genitalia partly occurs in the eighth abdominal segment, the study of evolution of this segment is very important.

In males, the most important evolutionary tendency of the eighth segment is its prolongation. This is true of all the groups of Gerridae. In some of the more primitive genera of Gerridae and Eotrechinae such as Charmatometrinae and Eotrechus the 8th segment itself has never become appreciably prolong. In *Onychotrechus*, *Chimarrhometra*, and *Amemboa* the seventh segment is not greatly modified in shape, the eighth segment has also not much modified apart from its prolongation. A similar condition is also observed in *Limnometra*, *Tenagonus* (s.str.) complex. In other genera of Gerrinae evolution has proceeded further to the point where the ventral surface of the segment is more or less greatly modified. In Cylindrostethinae the basal ventral region has become more and more depressed and the ventral apical margin has become progressively asymmetrical with the development of a process on the one side of the apical margin. In *Gerris* s.str. the ventral surface of the 8th segment has become more and more longitudinally elevated in the middle in more specialized species. In *Limnogonus* the ventral apical margin has undergone modification with the formation of the processes of various shapes in the middle. In *Tenagonus* s.str. the ventral surface, as well as the ventral apical margin, is curiously modified. In Ptilomerinae the most primitive 8th segment is found in *Rheumatogonus* in which the segment is not appreciably prolonged in the species examined.

In Ptilomera and Heterobates there is found a depression in the basal region of the ventral surface as in some genera of Gerrinae. In Heterobates found a median longitudinal elevation which is comparatively more pronounced in *Gerris* s.str. of Gerrinae. In Rhagodotarsinae the 8th segment is greatly prolonged and possesses a longitudinal sulcus in the middle. In Halobatinae, two pairs of processes dorsolaterally and ventrolateral have become more and more conspicuous in *Asclepios* and *Halobates*.

The ninth tergite in male in Gerridae is rather Cylinder, and the lateral margins are parallel to one another as they are in more primitive genera such as Eotrechus. The tergite has undergone various modifications. In Gerrinae the suranal plate is simple or feebly widened basally in most genera. Conspicuous modifications of the lateral margin are seen in *Amemboa*. In *Amemboa* the basal lateral process has become more and more conspicuous and in some specialized species of the genus there occurs an additional pair of processes inside the lateral pair of spinous processes. In *Onychotrechus* and *Chimarrhometra* no conspicuous modification of the basal lateral margin of the suranal plate is observed. The most distinct modification of suranal plate has occurred in Cylindrostethinae in which the basal lateral margin has become modified progressively with the production of asymmetrical processes. In Ptilomerinae the suranal plate is dilated behind its middle. The dilation is more conspicuous in *Ptilomera*. In Halobatinae the process of modification of the basal to

lateral region of the suranal plate progresses gradually. A highly generalized condition is observed in *Asclepios* and *Halobates*. In Rhagadotarsinae the suranal plate is somewhat dilated but no distinct modification is seen.

The loss of parameres has occurred independently in some or all genera of all subfamilies except for Ptilomerinae. In Cylindrostethinae the parameres have virtually lost. In Eotrechinae the parameres are well developed in Eotrechus short but robust in Onycho and completely lost in *Amemboa*. The parameres are greatly developed in *Chimarrhometra*. In *Amemboa* the basal lateral region of suranal plate is modified into a conspicuous process but the parameres are absent. In Charamatometrinae the parameres are simple. In Ptilomerinae the parameres have been retained in all genera and have undergone modification apically. In Halobatinae the parameres are distinctly retaining in *Asclepios* but are reduced in unrecognizable in *Halobates*. In general, the parameres in Gerridae have an overall tendency to be lost. The shape of paramere where present, offers an excellent specific character. The presence and absence of parameres are constant in most genera.

Prolongation of pygophore is one of the most important aspects of Gerridae. In some species of Halobatinae, the pygophore related laterally towards the right. The apical margin of pygophore is modified in various species of *Amemboa* and *Chimarrhometra*. In the species of *Metrocoris* of Halobatinae, the apical half of pygophore is greatly modified. The degree of rotation and demodification of pygophore apical margin varies considerably in various species even within the seven genera and hence forms an important character at the species level than at the generic level.

The styloid are found only in Eotrechus and their presence represents a primitive condition because the structure tends to be either fused to the pygophore or lost in more specialized species of the Gerridae.

The endosoma showed well differentiated sclerized plate in its apical plate in its apical segment. These plates are dorsal, apical, lateral, basal and ventral. The various plates and their sclerotization are quite a good taxonomic character at the species level in the family.

A well-developed ovipositor is a primitive condition in Heteroptera. In the Gerridae, the well form long ovipositor is present in only Rhagadotarsinae in which it serves for the insertion of eggs in the tissue of the plant. In this subfamily, the first and Second valvulae are greatly prolonged, but the basic structural plate is the same as in other subfamilies of the Gerridae. The rami of the first and second valvulae are attached to the black subtriangular plate at the apex of the ninth tergite. A second valvifer, as well as third valvulae, have been lost as in the subfamilies. In all the subfamilies of Gerridae, the first and second valvulae are well developed than in Rhagadotarsinae. The first valvulae either are not differentiated into an outer and inner lobe or are so differentiated only apically. In Gerrinae and Halobatinae they are well differentiated

into outer and inner lobes. The inner lobe is usually attached with the vulva. The ramus of first valvulae has shifted its point of attachment to the outer margin in various species and genera in the family. Second valvulae is usually pointed apically and form a sheath H-above the first valvulae. The valvulae are often apically being free from each other. The vestigial third valvulae are retained only in Charamatometrinae. The apical margin of intervalvular membrane is highly sclerotized in Cylindrostethinae but membranous or thickly sclerotized in Gerrinae. The study of the female genitalia offers excellent taxonomic characters at the subfamily level in the family Gerridae.

References

- [1]. Bonhag, P.F. and Wick, J.R. (1953). The functional anatomy of the male and female reproductive systems of the milkweed bug, *Oncopeltus fasciatus* (Dallas) (Heteroptera: Lygaeidae). *J. Morphol.*, 93: 177-283. doi: 10.1002/jmor.1050930202.
- [2]. Dupuis, C. & Carvalho, J.C.M. (1956). Heteroptera. In Tuxen, S.L., ed. Taxonomist's glossary of genitalia in insects. Copenhagen: Ejnar Munksgaard.
- [3]. Gyllensvärd, N. (1968). Beitrag zur Kenntnis der geographischen Verbreitung der europäischen Hemiptera Heteroptera. *Opuscula Entomologica*, 32(3): 273-278.
- [4]. Heymons, R. (1899). Beiträge zur Morphologie und Entwicklungsgeschichte der Rhynchoten. *Nova Acta. Abh. kaisl. Leop.-Carol. dt. Akad. Naturf. Halle* 74(3): 353-456.
- [5]. Kirby, W.F. (1891). Catalogue of the described Hemiptera, Heteroptera and Homoptera of Ceylon, based on the collection formed (chiefly at Punduloya) by Mr. E.E. Green. *J. Linn. Soc. (Zool.)*, 24: 72-76, pl. 4-6.
- [6]. Matsuda, R. (1955). The morphological and taxonomic significance of the basal abdominal segments in Hemiptera-Heteroptera. *The Pan-Pacific Entomologist*, 31(2): 73-74.
- [7]. Matsuda, R. (1958). On the Origin of the External Genitalia of Insects, *Annals of the Entomological Society of America*, 51(1): 84-94, <https://doi.org/10.1093/aesa/51.1.84>.
- [8]. Matsuda, R. (1960). Morphology, evolution and a classification of the Gerridae (Hemiptera-Heteroptera). The University of Kansas Science Bulletin, 41: 25-632.
- [9]. Paiva, C.A. (1919). Rhynchota from the Garo Hills, Assam. *Records of the Indian Museum*, 16, 350-377.
- [10]. Royer, M. (1925). Notes synonymiques (Hem.) 3e partie. *Bulletin de la Societe Entomologique de France Paris*, 91-93.
- [11]. Riley, C.F. (1925). Some aspects of the general ecology and behavior of the water-strider, *Gerris*

- rufoscutellatus* Latreille. *Entomologist's Record and Journal of Variation*, 37: 65-72, 86-93, 107-115.
- [12]. Snodgrass, R.E. (1933). Morphology of the insect abdomen. II. The genitalia ducts and the ovipositor. *Smithsonian Miscellaneous Collections*, 89: 1-148.
- [13]. Snodgrass, R.E. (1935). Principles of Insect Morphology. McGraw-Hill Book Company, pp. 667.
- [14]. Snodgrass, R.E. (1958). A revised interpretation of the external reproductive organs of male insects. *Smithsonian Miscellaneous Collections*, 135(6): 1-60.