



Correlations between niche selection and lengthwise modification of legs of freshwater aquatic Hemipteran insects– an evolutionary consequence

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Abstract

Freshwater aquatic hemipteran insects are often called ‘true bug’, belongs to the suborder Heteroptera. Scientists were in agreement that they were evolved in Triassic period of Mesozoic era. Although, they were secondarily adapted to aquatic life, their modified physio-morphological characters enable them to adjust in the new environment and help them to occupy almost all possible niches. Of all these changes, leg modifications showed promising effects. With modified leg structures, present day hemipteran bugs can walk, swim, grasp prey, able to escape from predators and lead a successful life. Present study deals with evaluation of lengthwise modifications of three pairs of legs of hemipteran bugs in relation to their niche. They were randomly collected from 3 different strata of lentic water bodies away from human interference and grouped them as surface feeders-rowers and walkers (Gerromorphans), underwater swimmers (Nepomorphans) and bottom dwellers (Leptopodomorphans). Each pair of legs has been measured and data were tabled separately. It has been observed that, different species of bugs belongs to the same family, when occupied different niche underwent modifications differently. Hence, bugs from quite unrelated taxa found to be assembled in the same area exhibited similar pattern of leg modifications. In other words, so far as evolutionary divergence is concerned niche selection gains priority for these aquatic bugs.

Keywords: hemipteran bug, niche selection, morphometric study, lentic ecosystem

Introduction

It was Permian period of Palaeozoic era, when aquatic insects become diverse and colonized in different water bodies. Surprisingly, insects of phylogenetically quite unrelated taxa with different developmental pattern and feeding habit were associated with aquatic environment (Sinitshenkova, 2003) [21]. Of these, over 45000 species adopted to fresh water habitats (Sharma *et al.* 2020) [20]. Fossil record showed that freshwater aquatic hemipteran bugs were evolved in Triassic period of Mesozoic era (Popov, 1971; Damgaard, 2008) [17, 7]. Although, they are secondarily adapted to fresh water aquatic ecosystem (Basu and Subramanian, 2017) [4], during these long periods of time, they evenly occupied almost all the possible niche of fresh water ecosystem. Unlike other aquatic insects, both nymph and adult stages of aquatic Hemiptera occupy the same aquatic habitat and spent their entire life (Bouchard, 2004) [5]. Their habitat specificity and food preference led them to modify morphologically to adjust in a particular niche. Present day aquatic hemipterans have tackled all the constraints of living in aquatic environment by possessing several physio-morphological adaptations (Basu and Subramanian, 2017) [4]. Of all these changing morphological characters, leg modifications have gain momentum (Voshell, 2002) [23]. Apart from walking, swimming and support, legs enable the aquatic bugs to catch prey and escape from predators and make their life comfortable in aquatic environment. According to their food preference, these aquatic Hemipteran bugs were herbivores, carnivores, algae feeders, scrapers, detritivores and omnivores (Sinitshenkova, 2003) [21]. They have poor dispersal capabilities (Hungerford and Matsuda, 1958a, 1958b) and keep themselves confined to a particular niche and hence considered suitable for study of evolutionary aspects.

Despite being one of the dominant insect orders in fresh water ecosystem, morphological studies on these hemipteran bugs have received little attention in the Oriental region (Doke, *et al.* 2017) [9]. Present study deals with the Morphometric study to evaluate the length-wise modifications of three pairs of legs of freshwater aquatic Hemipteran bugs in relation to their niche selection.

Materials and Methods

Natural lentic ecosystems, devoid of excessive water current and away from human interference were taken into consideration. Aquatic hemipteran bugs were collected from three different sources from their natural habitats with the help of kick net and by hand picking. From each sources, they were randomly taken from three different strata of the lentic water bodies. Nine specimens from four families were collected from surface water and six species from three families were taken from underwater (limnetic zone) found in free swimming state or in attachment with the submerged vegetations. Other six specimens belong to five different families were collected from bottom (benthic zone), showing equally expertise in swimming as well as walking at the bottom. For convenience of study, the collected aquatic hemipterans were divided into 3 groups (infraorder) according to the classification made by Basu and Subramanian (2017) [4] on the basis of their niche and habitat preference. These were – ‘Gerromorpha’ (rowing and walking on the water surface), ‘Nepomorpha’ (expert underwater swimmers) and ‘Leptopodomorpha’ (Shore and Bottom dwellers). Collected specimens were separated accordingly and were placed in these 3 groups. Results were shown in 3 different Tables and Figures.

Legs were measured with scales at micrometer level. Binocular Microscopes were use for micrometry. Five

segments of each pair of legs were measured separately and then assembled to obtain maximum accuracy in total length. Each measurement has been repeated three times and the mean data were taken for statistical analysis.

Results and Discussions

Lengthwise measurements of three pairs of legs of nine species from four families of surface feeder (Gerromorpha) aquatic hemipteran bugs were enlisted in the table 1. All these bugs restricted their life activities on water surface only. Of these, five species were surface rowers and the remaining four were surface walkers, as shown in Figure 1 A and 1B respectively. Species from Gerridae family, *Gerris lacustris*, *Aquarius najas*, *Aquarius remigis*, *Ptilomera assamensis* and species from Veliidae family, *Rhagovelia sumatrensis* showed their mesothoracic legs (L2) longer than the other two pairs i.e. prothoracic and metathoracic (L1 & L3). Certainly, all these species showed expertise as surface rowers. They utilized L2 for propelling the body on water surface, while L3 acted as steering rudders (Andersen 1976; Voshell, 2002; Hu *et al.*2003; Khila *et al.*2014; Refki *et al.*, 2014)^[1, 23, 12, 16, 18]. In contrast, *Pseudovelia sexualis* (*Microvelia* spp.) from Veliidae family, *Mesovelia vittigera* species from Mesoveliidae family, *Hydrometra martini* from Hydrometridae family and *Micronecta striata* from Corixidae family exhibited their metathoracic legs (L3) longest. This indicated that they were able to retain the primitive characters of their terrestrial ancestors where metathoracic legs are invariably longest. Developments of some hair like accessory structures on the legs help them to maintain buoyancy on water surface.

Although they are the members of different families, all of them are adapted to walk on water surface, i.e. surface walkers. In all the specimens, regardless of surface rowers and walkers collected from water surface, showed their prothoracic legs (L1) shortest and engaged in capturing prey. As morphological adaptations of aquatic insects are closely related with behavioural adaptation (Elango *et al* 2021; Subramanian and Sivaramakrishnan 2007)^[10, 22], in this context, it can be claimed that, although both the groups are surface feeders, they exhibited vast differences in their leg morphology. Due to the advantageous character of elongation of L2, rowers can quickly spread out a large surface water niche in comparison to surface walkers (Andersen, 1976; Andersen, 1982; Damgaard *et al.* 2008a; Hu and Bush, 2010)^[1, 2, 8, 12]. Working on evolution of adaptive morphological traits of surface feeders, Refki, *et al.* (2014)^[18] marked that the transition of life from land to water surface seems to be associated with gradual lengthening of the legs. Regarding elongation of L2 in surface rowers, he stated that, they have evolved a novel adaptive morphology where the length of appendages has been reversed i.e. L2 is longer than L3. Working on adaptive radiation of water surface invaders (Gerromorphans) on genetic level, Khila *et al.* (2014) reported that lengthening of the legs were associated with the gene, Ubx (Ultrabithorax) and Ubx protein is responsible for such modifications on thoracic appendages. He also claimed that water surface rowers with elongated L2 has been considered as ‘Derived lineage’ with this advantageous character, which diversified from the ‘Basal lineage’, where surface walkers are still exist carrying ancestral trait.

Table 1: Lengthwise measurement of three pairs of legs of ‘surface feeder’ (Gerromorphans) aquatic Hemipteran bugs-

Sl. Nos.	Family	Sc. name	L1* Mean± SD (mm)	L2** Mean± SD (mm)	L3*** Mean± SD (mm)	Comments
1	Gerridae	<i>Gerris lacustris</i>	6.18±0.011	18.42 ±0.046	12.54±0.074	L2>L3>L1
2	Gerridae	<i>Aquarius najas</i>	4.61±0.017	14.08±0.054	10.66±1.816	L2>L3>L1
3	Gerridae	<i>Aquarius remigis</i>	4.47±0.012	15.43±0.069	12.61±1.824	L2>L3>L1
4	Gerridae	<i>Ptilomera assamensis</i> (Amyot &Serville, 1843)	13.18±0.035	24.20±0.057	23.23±0.010	L2>L3>L1
5	Veliidae	<i>Rhagovelia sumatrensis</i> (Lundblad,1933)	17.31±0.069	35.163±0.034	22.28±0.069	L2>L3>L1
6	Veliidae	<i>Microvelia</i> spp. <i>Pseudovelia sexualis</i> (Paiva,1917)	1.68±0.01	2.396±1.824	2.83±1.825	L3>L2>L1
7	Mesoveliidae	<i>Mesovelia vittigera</i>	10.076±0.83	24.023±0.010	32.17±0.086	L3>L2>L1
8	Hydrometridae	<i>Hydrometra martini</i>	4.266±0.022	5.366±0.014	7.18±0.017	L3>L2>L1
9	Corixidae	<i>Micronecta striata</i>	0.66±0.031	2.363±0.010	4.42 ±1.824	L3>L2>L1

*Prothoracic legs, **Mesothoracic legs, ***Metathoracic legs

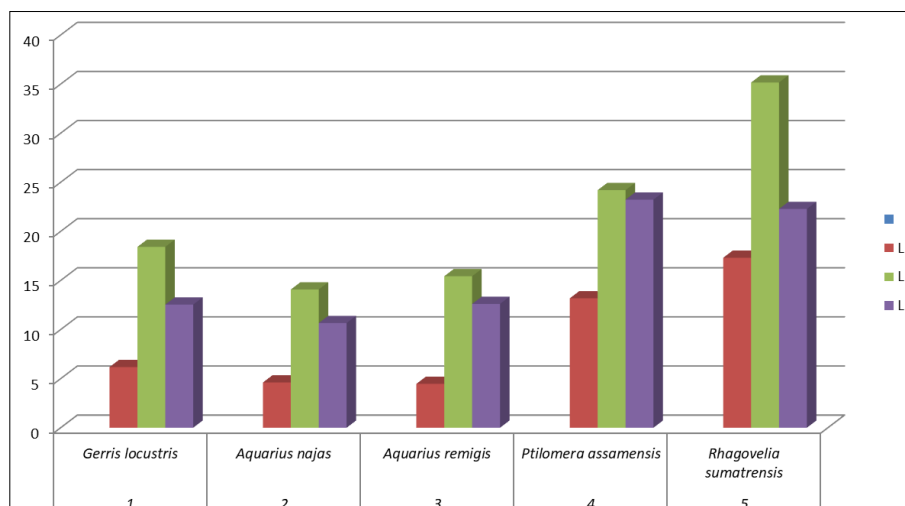


Fig 1 (A): Showing surface rowers where L2 is longest

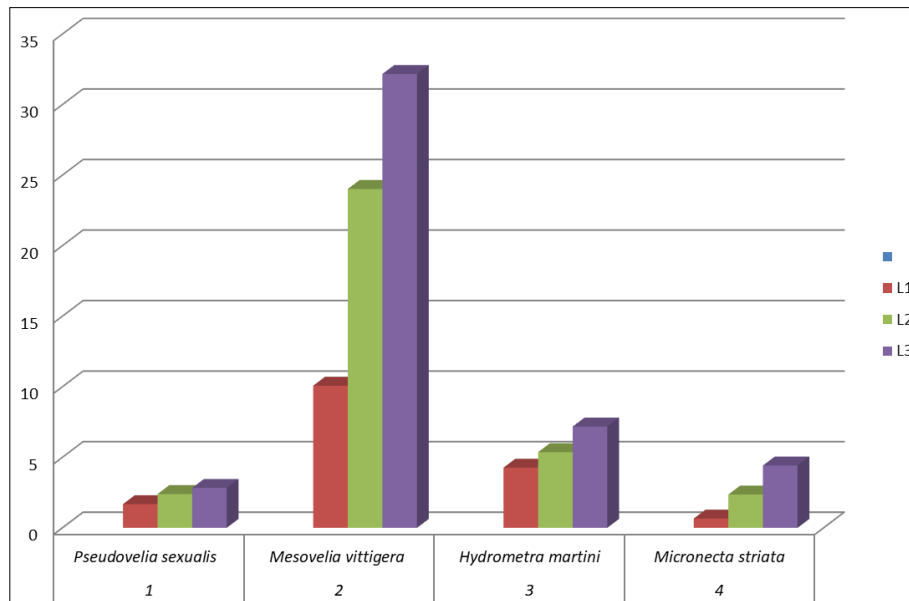


Fig 1(B): Showing surface walkers where L3 is longest L1-Prothoracic legs, L2-Mesothoracic legs, L3- Metathoracic legs

Table 2: Lengthwise measurement of 3 pairs of legs of ‘free swimmer’ (Nepomorphans) aquatic Hemipteran bugs –

Sl. Nos.	Family	Sc. name	L1*Mean± SD (mm)	L2** Mean± SD (mm)	L3*** Mean± SD (mm)	Comments
1.	Nepidae: Nepinae	<i>Laccotrephesruber</i> (Linnaeus 1764)	13.1±1.825	18.22±0.011	23.433±0.014	L3>L2>L1
2.	Nepidae: Nepinae	<i>Nepa cinerea</i> (Linnaeus 1758)	22.116±2.921	14.273±0.026	24.493±0.053	L3>L1>L2
3.	Nepidae: Ranatrinae	<i>Ranatra filiformis</i>	13.343±0.045	21.456±0.069	26.243±0.022	L3>L2>L1
4.	Nepidae: Ranatrinae	<i>Ranatra chinensis</i>	14.323±0.014	20.146±0.026	23.356±0.037	L3>L2>L1
5.	Nepidae: Ranatrinae	<i>Ranatra gracilis</i> (Dallas, 1850)	9.667±0.045	21.256±0.017	23.170±0.045	L3>L2>L1
6.	Corixidae	<i>Notonecta glauca</i>	1.32±0.010	2.41±0.045	16.316±2.309	L3>L2>L1

*Prothoracic legs, **Mesothoracic legs, ***Metathoracic legs

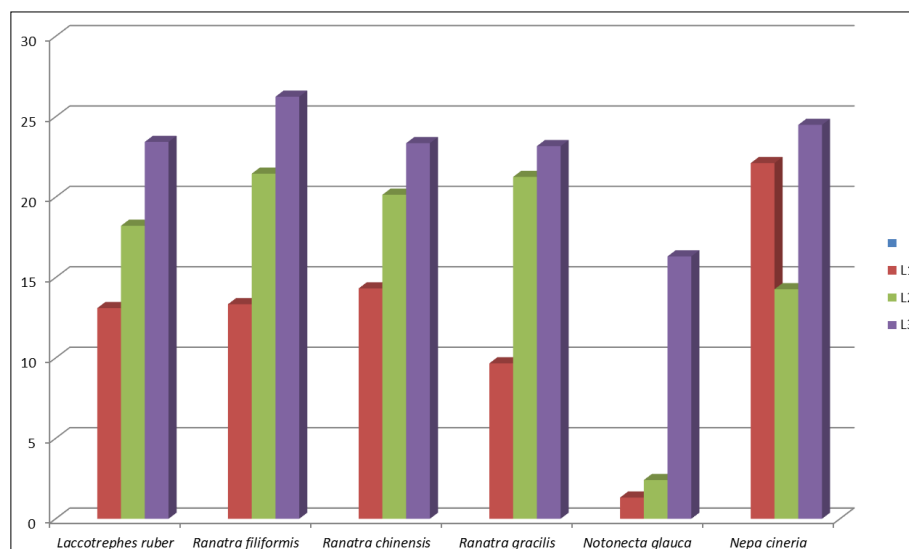


Fig 2: Lengthwise measurement of 3 pairs of legs of Nepomorphans hemipteran bugs showing L3>L2>L1, with exception in *N. cineria* where L3>L1>L2.L1-Prothoracic legs, L2-Mesothoracic legs, L3-Metathoracic legs

Table 2 and Fig 2 represented data of morphometric study of three pairs of legs of Nepomorphans hemipteran bugs. Five species from Nepidae family and one from Corixidae family have been taken for observation. Of these, *Laccotrephes ruber* and *Nepa cineria* belongs to the subfamily Nepinae, and *Ranatra filiformis*, *Ranatra chinensis* and *Ranatra gracilis* were of the subfamily Ranatrinae of family Nepidae, *Notonecta glauca* belongs to the family Corixidae. All of them exhibited elongation of metathoracic (L3) legs followed by mesothoracic (L2) and

Prothoracic (L1) legs respectively with an exception in *Nepa cineria*, where L2 were the smallest of all. Nepomorphans were the true aquatic bugs, exhibiting expertise in under water living (Basu and Subramanian, 2017) [4]. Working on *Notonecta glauca*, Reynaldi *et al.* (2011) observed that this expert underwater swimmer utilize long hind legs for propelling the body under water. Available information suggested that unlike other members of Nepidae family, *Nepa cineria* is a poor swimmer. Majority of the time it walks slowly on the submerged

vegetations in search of food and suitable substratum for laying eggs. Time to time it also comes out of water for replenish oxygen. They are also strong flyer. Doke *et al* (2017) ^[9] opined that attribution of differential functions to the single organ is responsible for such type of allometric growth pattern. Morphometric study of legs of three species of subfamily Ranatrinae showed that their L2 and L3 were comparatively longer than the L1. Bailey (1986) opined that they utilize their long L2 and L3 alternately for swimming, while comparatively short, stout L1 for grasping prey. Ranatrinae has been recorded in high densities with several new species from oriental region (Chen, *et al.* 2004) ^[6].

Aquatic hemipteran bugs from different families were collected from bottom strata and taken for Morphometric studies of legs. Data were placed in the table 3 and Figure 3. Of these, *Diplonychus rusticus* and *Lethocerus indicus* from Belostomatidae family, *Pelocoris femoratus*, *Aphelocheirus oestivalis*, *Sigara distincta*, *Ranatra linearis* from Naucoridae, Aphelocheiridae, Corixidae and Nepidae family respectively were examined. All these were equally adapted for swimming as well as bottom dwelling. The fact was that,

regardless of taxonomic relationship, all these bugs showed remarkable similarities in morphometry of legs, where any two pairs of legs were nearly equal in length. Table 3 showed that the specimens *Diplonychus rusticus*, *Lethocerus indicus*, *Pelocoris femoratus*, *Aphelocheirus oestivalis* have their L2 nearly similar with L1. While *Sigara distincta* and *Ranatra linearis* possess their L2 nearly similar with L3. Khila *et al* (2014) ^[16, 18] opined that major changes in total leg lengths were associated with niche diversification. Subramanian *et al.* (2007) ^[22] suggested a close relationship between morphological adaptation and behaviour of aquatic insects. Therefore, it can be assumed that, as these bugs from taxonomically unrelated families were assembled in the same strata and adopted the same behavioural pattern, it is obvious that they follow the same route of morphological adaptations. Jill and Barbara (2013) ^[15] mentioned that locomotory activities of aquatic insects also depended upon the sizes of the body and appendages. Probably, this may be the reason why the members of variable sizes of Corixidae family occupied almost all strata of fresh water ecosystem.

Table 3: Lengthwise measurement of 3 pairs of legs of ‘bottom dwelling’ (Leptopodomorphan) Hemipteran bugs.

Sl. Nos.	Family	Sc. name	L1* Mean± SD (mm)	L2** Mean± SD (mm)	L3*** Mean± SD (mm)	Comments
1.	Belostomatidae	<i>Diplonychus rusticus</i>	7.263±0.043	8.773±0.036	15.203±0.021	L1~L2<L3
2.	Belostomatidae	<i>Lethocerus indicus</i>	37.133±0.019	36.92±0.080	54.363±0.170	L1~L2<L3
3.	Naucoridae	<i>Pelocoris femoratus</i>	15.28±0.035	16.283±0.089	24.54±0.011	L1~L2<L3
4.	Aphelocheiridae	<i>Aphelocheirus oestivalis</i> (Fabricius, 1794)	4.986±0.053	5.436±0.047	9.62±0.012	L1~L2<L3
5.	Corixidae	<i>Sigara distincta</i>	2.583±0.013	8.703±0.026	8.753±0.010	L2~L3>L1
6.	Nepidae: Ranatrinae	<i>Ranatra linearis</i>	12.356±0.042	36.25±0.130	36.346±1.824	L2~L3>L1

*Prothoracic legs, **Mesothoracic legs, ***Metathoracic legs

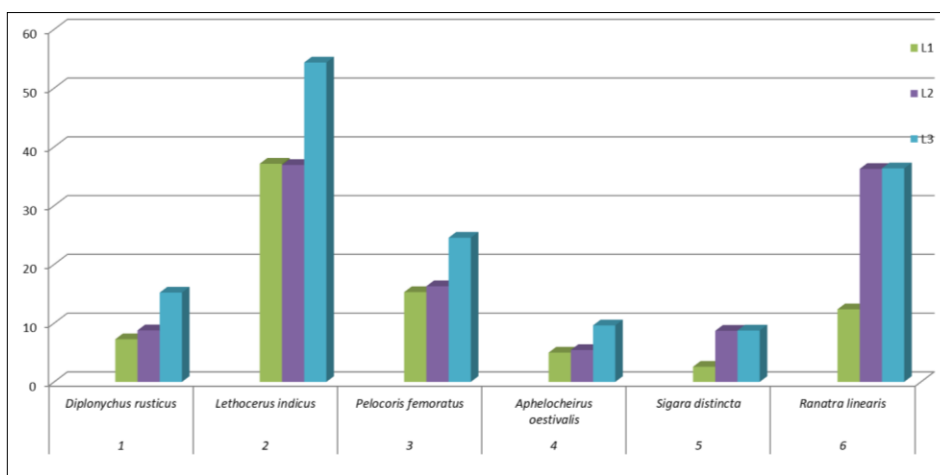


Fig 3: Lengthwise measurement of 3 pairs of legs of bottom dwelling bugs showing similarities of any two pairs. L1-Prothoracic legs, L2-Mesothoracic legs, L3- Metathoracic legs

Conclusion

Present study indicates that, lengthwise leg modifications of hemipteran aquatic bugs are closely related to their niche selection. It has been noted that bugs belongs to different families when occupy the same niche, exhibited similar locomotory behavior and modified their legs accordingly. On the other hand, same family members occupying different strata of water bodies exhibited differential growth pattern of their legs. Exceptions found were assumed to be related with behavior as shown by surface feeders, where ‘walkers’ move slowly with elongated L3 (ancestral

character), while ‘rowers’ move and spread at a high speed with development of new character, *ie* elongation of L2. Nepomorphan were underwater swimmers utilized their long L3 as oars. Bottom feeders claimed equal expertise in swimming and walking and hence exhibited nearly equal leg length in any two pairs of legs.

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Author contribution

¹did identification of specimens and manuscript preparation.

^{2&3}did specimens collection and measurement of leg lengths.

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