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COMMUNICATION

Aquatic Hemiptera inhabiting rice fields in Karaikal, Puducherry, India

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Abstract: The present investigation was taken up to record the diversity and abundance of aquatic hemipterans in an irrigated rice ecosystem during kharif 2019 and rabi 2019–2020. The aquatic hemipterans were collected using a D-frame dip net at weekly intervals. This study revealed 21 species under 13 genera and nine families of Hemiptera in irrigated rice fields during kharif 2019 and rabi 2019–2020. *Micronecta scutellaris* (Stål, 1858) and *Anisops sardeus* Herrich-Schäffer, 1850 were the dominant species in both seasons. Corixidae and Notonectidae were the most abundant families. Species diversity was maximum in kharif 2019, while species richness was maximum during rabi 2019–2020. Multiple linear regression indicated that all the physicochemical characteristics and weather parameters together were responsible for significant variation in the occurrence of Corixidae (53.60%) and Notonectidae (82.40%). Based on our research, we found that rice fields serve as suitable habitats and play a crucial role in supporting diverse range of aquatic hemipterans.

Keywords: Biodiversity indices, correlation, irrigated rice ecosystem, kharif, multiple regression, rabi, relative abundance.

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Author contributions: MK—concept, supervision & reviewing; LG—field sampling, collection of data, analysis and preparation of manuscript.

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INTRODUCTION

Rice *Oryza sativa* L. is a major cereal crop and is consumed as a staple food by the majority of the population in India (Priya et al. 2019). It is also a major crop cultivated in the Cauvery delta region of Tamil Nadu, including Karaikal district (which lies at the tail end of the delta region), Union Territory of Puducherry. Aquatic insects can thrive and form a wide food chain in the rice ecosystem due to the availability of water during the entire growing season in irrigated rice fields (Bambaradeniya et al. 2004). Terrestrial insects were the primary focus in the majority of studies on insect diversity which related to rice fields (Jauharlina et al. 2019). However, the aquatic fauna of irrigated rice fields was extensively studied in China (Zhu et al. 2017), India (Gopianand & Kandibane 2022), Indonesia (Wakhid et al. 2020), Japan (Natuhara 2013), Philippines (Yano et al. 1981), and Thailand (Maneechan & Prommi 2023). Cochard et al. (2014) reported 39 aquatic arthropods belonging to seven orders were collected from rice fields in the central part of Thailand. A total of 45 aquatic insect species from 20 families and seven orders were recorded in rice fields in Bogor, West Java, Indonesia (Wakhid et al. 2020).

Globally, around 4,656 species of aquatic and semiaquatic Heteroptera are recorded, which constitutes three infraorders, 20 families, and 326 genera (Polhemus & Polhemus 2008). In India, a total of 325 species have been recorded, which constitutes 84 genera and 18 families of aquatic and semi-aquatic Hemiptera (Basu & Subramanian 2017). A total of 20 species, comprising 15 genera, and nine families of the aquatic and semi-aquatic Heteroptera were reported in Puducherry (Thirumalai & Kumar 2005). Some of the aquatic hemipterans are natural predators in rice fields, such as the species belonging to the families, Gerridae, Hydrometridae, Mesoveliidae and Veliidae, which have been reported to prey on brown planthopper (Heong & Hardy 2009). A total of eight families of aquatic hemipterans (i.e., Hydrometridae, Mesoveliidae, Micronectidae, Notonectidae, Veliidae, Nepidae, Gerridae, and Pleidae) were recorded in the rice fields at the Khon Kaen province, northeastern Thailand during June to October 2015 (Thongphak & Iwai 2016).

Considering the importance of the hemipterans in ecosystem functioning as prey, predators, scavengers, and bioindicators (Steward et al. 2022), it is essential to know the available aquatic hemipterans in the rice ecosystem. So, there is an immense scope to study the community structure of aquatic hemipterans in rice ecosystem. Hence, the present investigation was taken up to record the diversity and abundance of aquatic hemipterans in an irrigated rice ecosystem of Pandit Jawaharlal Nehru College of Agriculture and Research Institute (PAJANCOA&RI), Karaikal in two seasons.

MATERIALS AND METHODS

The study was undertaken during kharif 2019 and rabi 2019–2020. The aquatic hemipterans were collected from the irrigated rice fields at weekly intervals from July 2019 to February 2020 in the eastern farm of PAJANCOA&RI (10.9488°N, 79.7813°E & 4 m) (Figure 1). The kharif cropping season starts from July to October and the rabi season is from October to March. The study area is expected to receive an average annual rainfall of 126 cm, plus irrigation water from the Mettur dam of Tamil Nadu.

The aquatic hemipterans were collected with a D-frame dip net 12” wide x 10” long (305 x 254 mm) and 22” in depth, made up of white nylon cloth with a 500 µm mesh. The handle was about 30” in length and 32 mm in diameter. The collections were carried out in the early morning from 0060 h–0090 h at weekly intervals from after the transplanting to before harvest. A total of 25 sweeps were made in 25 selected sites in the rice fields at random (Figure 1). The net was passed through the standing water in the rice fields and then shaken in the standing water to remove silt and mud. The leftover contents of the net including the trapped aquatic insects were transferred to a white pan 27.5 x 35 x 5.5 cm with about 2 cm of water in it, and the aquatic insects were sorted out after complete washing. Most of the surface swimming insects like riffle bugs were collected by dragging a dip net on the water surface (half submerged) and then they were picked up by hand and put into vials containing 70% ethanol (Wakhid et al. 2020; Gopianand & Kandibane 2022). The collected specimens after sorting out to family level were stored in 30 ml vials containing 70% ethanol with a few drops of glycerine and preserved in insect storage boxes for identification to species level (Walker et al. 1999). The collected aquatic Hemiptera were identified with the standard literature of Bal & Basu (1994) and Thirumalai (2004). Identification of aquatic hemipterans was done by Dr. K.A. Subramanian (Scientist-D), Zoological Survey of India. All images of identified aquatic hemipterans were captured with Nikon D5300 DSLR camera and Leica EZ4E stereo zoom microscope.

The weekly average meteorological parameters were

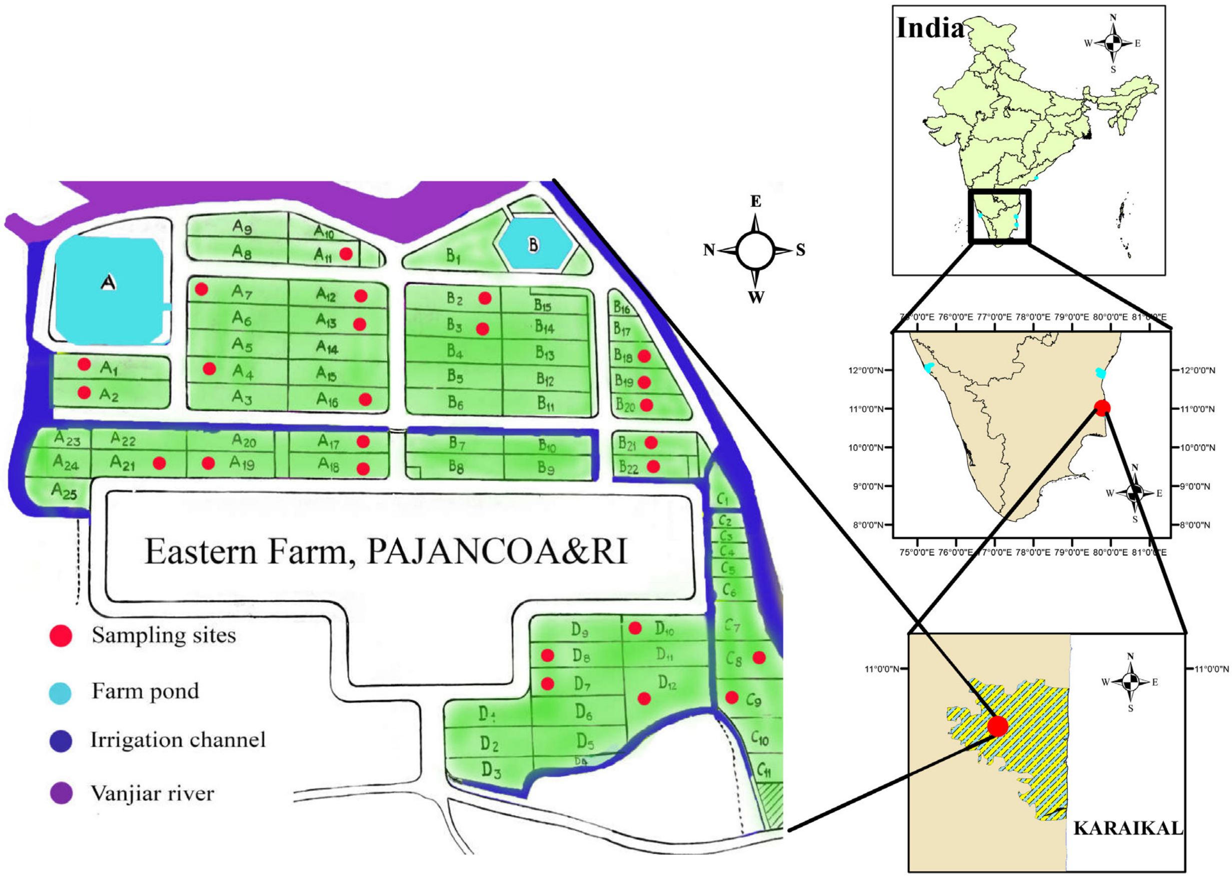

Figure 1. Study area (PAJANCOA & RI, Karaikal, U.T. of Puducherry, India) with sampling sites.

calculated from the daily meteorological data of the study area was obtained from the agrometeorological observatory, Department of Agronomy, PAJANCOA&RI, Karaikal. Physico-chemical parameters such as water temperature (WT), pH and electrical conductivity were recorded using a mercury bulb thermometer, digital pH meter (pH 700- Eutech instruments), and conductivity meter (CON 700-Eutech instruments), respectively. Based on the relative abundance % (RA), the species were classified as Subrecedent (<1), Recedent (1.1–3.1), Subdominant (3.2–10), Dominant (10.1–31.6), and Eudominant (> 31.7) (Engelmann 1978).

The diversity indices were analysed namely Simpson's index of dominance (D) calculated using the formula

$$D = \sum \frac{[N_i(N_i - 1)]}{[N_t(N_t - 1)]}$$

(Where, N_i = the number of individuals in the i^{th} species; N_t = the total number of individuals in the sample) and Simpson's index of diversity (λ): 1 – D (Simpson 1949). Shannon diversity index was determined by $H' = \Sigma P_i \ln P_i$(Where, $P_i = n/N$; P_i = the proportion of individuals in the i^{th} species; n = number of individuals belonging to i^{th} species; N = Total number of individuals) (Shannon 1948). Evenness indices are determined by (E) = H / ln S (Where, H = Shannon's index; S = Total number of species) (Ludwig & Reynolds 1988). Menhinick's richness index is calculated from the ratio of the number of taxa to the square root of sample (Menhinick 1964). Margalef index was determined by using the formula: R1 = (S-1) / ln N (Where, S = Total number of species; N = Total number of individuals) (Margalef 1963). Equitability-J was calculated using $J = H / H_{max}$ (where, H is the Shannon's diversity index; H_{max} is different for each community and depends on species richness) (Pielou 1975). The Berger-Parker index $d = N_{max} / N$ (where N_{max} is the number of individuals in the most abundant species) (Berger & Parker 1970). Correlation and multiple regression were used to predict the effect of physicochemical characteristics and weather parameters on the abundance of aquatic hemipterans. All analyses were done with PAST version 4.0 (Hammer et al. 2001) and Agricolae R package version 1.4.0 (Mendiburu 2015).

RESULTS

A total of 21 aquatic hemipteran species were recorded. During kharif 2019, a total of 2,743 individuals were collected, which comprised 13 species under nine genera and eight families (Image 1 a–u). As per Engelmann scale, *Micronecta scutellaris* (Stål, 1858) and *Anisops sardeus* Herrich-Schäffer, 1850 were eudominant species with 43.5 and 37.1% relative abundance, respectively. Among the eight families, Corixidae was the most abundant family (47.7%), followed by Notonectidae (45.5%) (Table 1). A total of 4,608 individuals of aquatic hemipterans were collected during rabi 2019–2020 which comprised 17 species under 13 genera and nine families (Image 1 a–u). Among the 17 species, *A. sardeus* and *M. scutellaris* (were the eudominant species with the highest relative abundance of 46.4% and 42.4%, respectively. Out of the nine families Notonectidae and Corixidae were eudominant with the highest relative abundance of 47.2% and 43.7%, respectively (Table 1).

In both seasons, the diversity index values for dominance (D) were less than one and it was due to the higher representation of two dominant species, i.e., *A. sardeus* Herrich-Schäffer, 1850 and *M. scutellaris* (Stål, 1858). Based on the dominance indices values, higher dominance was recorded in the rabi season compared to the kharif season. The highest values for diversity indices of Simpson index (λ) (0.667), Shannon diversity index (H') (1.441), and Menhinick (0.248) were recorded in kharif 2019. Higher Shannon index values indicate higher diversity. In this case, the kharif season had slightly higher diversity and the rabi season had higher species richness. The maximum dominance based on the Margalef index (1.897) and Berger Parker index (0.464) was recorded in rabi 2019–2020 (Table 1). The evenness—e^H/S and equitability—J values were calculated for the kharif and rabi seasons, resulting in 0.325 and 0.202 for evenness, and 0.562 and 0.435 for equitability—J, respectively (Table 1). The higher evenness observed in the kharif season suggests a more balanced distribution of species abundances compared to the rabi season.

The family Corixidae showed a significant ($p<0.05$) negative correlation (-0.63) with electrical conductivity (EC), atmospheric temperature (-0.62), water temperature (-0.58) and positive significant correlation with relative humidity (0.76). The family Mesoveliidae expressed a significant negative correlation (-0.66) with water temperature throughout the study period. The family Notonectidae alone showed a positive significant ($p<0.05$) correlation with relative humidity (0.76) and rainfall (0.66). The families Notonectidae, Pleidae and Veliidae showed significant negative correlation with pH (-0.62, -0.64, -0.58) and EC (-0.75, -0.61, -0.63), respectively (Table 2). Multiple linear regression also indicated that all the physico-chemical characteristics together were responsible for significant variation in the occurrence of Corixidae (53.60%) and Notonectidae (82.40%) (Table 2).

DISCUSSION

Nine species of aquatic Hemiptera were recorded in both seasons, and four species of Kharif 2019 were not recorded during Rabi 2019–2020. It indicated that the nine species of aquatic Hemiptera were common species found in irrigated rice ecosystems, and had the ability to survive under the fluctuating environmental conditions. The other four species, which had favourable climatic conditions during Kharif 2019, appeared only in that season, and not in rabi, due to unfavourable environmental conditions (Table 1). Das & Gupta (2012) reported 14 species of aquatic Hemiptera in Assam. Thirumalai & Kumar (2005) recorded 20 species of aquatic and semi-aquatic Hemiptera from the wetlands of Karaikal and Pondicherry. In the present study, the maximum diversity index was recorded during rabi season (mid-November to April), which is in contrast with the results of Das & Gupta (2012) who stated that Shannon's index value for pre-monsoon (0.93), monsoon (0.87), post-monsoon (0.86), and winter (0.92) during March 2007 to February 2008 in Bharambaba temple pond, Assam.

Anisops sardeus Herrich-Schäffer, 1850 was the eudominant species with the highest relative abundance during rabi 2019–2020. It was inferred that the high relative abundance of *A. sardeus* might be due to the continuous stagnation of rainwater in the rice fields till the harvest of crops. During rabi 2019–2020, it was observed that *A. sardeus* mainly feeds on the larvae of chironomids, mosquitos, fallen leaf-folder larvae (*Cnaphalocrocis* spp.) and other rice pests. It was also found that the canopy of the rice did not allow sunlight to fall over the surface of the water, which favours the abundance of aquatic hemipterans in the rice crop (Kandibane et al. 2007). Moustafa et al. (2017) reported that *A. sardeus* was abundant in rice fields of Egypt, due to high content of organic matter. Tripole et al. (2008) noted that a high density of Notonectidae was found in winter and rainy season, which had favourable environmental conditions for their abundance relative

Table 1. Diversity and dominance of aquatic hemipterans in an irrigated rice ecosystem.

	Taxa	kharif 2019		rabi 2019–2020		Total
		RA (%)	Status of dominance*	RA (%)	Status of dominance*	
I	Belostomatidae (Water bugs)					
1.	*Diplonychus annulatus* (Fabricius, 1781) (Image 1a, nymph)	-	-	0.13	Subrecedent	6
2.	*D. rusticus* (Fabricius, 1871) (Image 1b)	0.44	Subrecedent	0.48	Subrecedent	34
3.	*Lethocerus indicus* (Lepeletier & Serville, 1825) (Image 1c)	-	-	0.07	Subrecedent	3
II	Corixidae (Water boatmen)					
1.	*Micronecta scutellaris* (Stål, 1858) (Image 1d)	43.46	Eudominant	42.43	Eudominant	3147
2.	*M. ludibunda* Breddin, 1905 (Image 1e)	4.23	Subdominant	-	-	116
3.	*Sigara pectoralis* Fieber, 1851 (Image 1f)	-	-	1.24	Recedent	57
III	Gerridae (Water striders)					
1.	*Aquarius adelaidis* (Dohrn, 1860) (Image 1g)	1.1	Recedent	0.48	Subrecedent	52
2.	*Limnogonus fossarum* (Fabricius, 1775) (Image 1h)	0.97	Subrecedent	0.78	Subrecedent	63
3.	*L. nitidus* (Mayr, 1865) (Image 1i)	0.15	Subrecedent	-	-	4
4.	*Rhagadotarsus kraepelini* Breddin, 1905 (Image 1j)	-	-	0.28	Subrecedent	13
IV	Hydrometridae (Water measurer)					
1.	*Hydrometra greeni* Kirkaldy, 1898 (Image 1k)	1.46	Recedent	0.93	Subrecedent	83
V	Mesoveliidae (Water treaders)					
1.	*Mesovelia vittigera* Horváth, 1895 (Image 1l)	1.49	Recedent	0.56	Subrecedent	67
2.	*M. horvathi* Lundblad, 1933 (Image 1m)	-	-	0.50	Subrecedent	23
VI	Nepidae (Water Scorpions)					
1.	*Laccotrephes griseus* (Guérin-Méneville, 1835) (Image 1n)	0.77	Subrecedent	-	-	21
2.	*Ranatra elongata* Fabricius, 1790 (Image 1o)	-	-	0.46	Subrecedent	21
3.	*R. varipes* Stål, 1861 (Image 1p)	-	-	0.55	Subrecedent	27
VII	Notonectidae (Back swimmers)					
1.	*Anisops sardeus* Herrich-Schaeffer, 1849 (Image 1q)	37.11	Eudominant	46.35	Eudominant	3154
2.	*A. lundbladiana* Lansbury, 1962 (Image 1r)	3.46	Subdominant	0.82	Subrecedent	133
3.	*A. nasutus* Fieber, 1851 (Image 1s)	4.96	Subdominant	-	-	136
VIII	Pleidae (Pygmy back swimmer)					
1.	*Paraplea frontalis* (Fieber, 1844) (Image 1t)	-	-	3.2	Subdominant	146
IX	Veliidae (Riffle bugs)					
1.	*Microvelia douglasi* Scott, 1874 (Image 1u)	0.40	Subrecedent	0.74	Subrecedent	45

Diversity indices	kharif 2019	rabi 2019–2020
Species richness	13	17
Individuals	2743	4608
Dominance- D	0.333	0.397
Simpson's diversity index (λ)	0.667	0.604
Shannon diversity index (H')	1.441	1.233
Menhinick's richness index	0.248	0.250
Margalef's richness index	1.516	1.897
Evenness_e^H/S	0.325	0.202
Equitability- J	0.562	0.435
Berger-Parker dominance index	0.435	0.464

*—As per Engelmann scale (Engelmann 1978) | Relative abundance % (RA): <1—Subrecedent | 1.1–3.1 —Recedent | 3.2–10—Subdominant | 10.1–31.6—Dominant | > 31.7—Eudominant.

Table 2. Correlation and regression for aquatic Hemiptera with weather parameters in rice ecosystem.

Family	pH	EC	AT	WT	RH	RF	Regression equation	R^2
Belostomatidae	-0.37	-0.36	-0.47	-0.51	0.38	0.21	$Y = 19.82 -0.23X_1 +0.62X_2 -0.15X_3 -0.36X_4 -0.05X_5$	0.309#
Corixidae	-0.50	-0.63*	-0.62*	-0.58*	0.61*	0.35	$Y = -36.45 -14.61X_1 -28.57X_2 +1.56X_3 +2.07X_4 +2.14X_5 +0.05X_6$	0.536*
Gerridae	-0.01	-0.26	-0.05	-0.16	0.10	0.09	$Y = -27.73 +1.31X_1 -2.89X_2 +1.01X_3 -0.74X_4 +0.11X_5 +0.01X_6$	0.220#
Hydrometridae	-0.05	-0.08	-0.02	-0.15	0.05	-0.09	$Y = -3.41 +0.35X_1 -0.35X_2 +0.40X_3 -0.52X_4 +0.03X_5$	0.074#
Mesoveliidae	-0.25	-0.24	-0.27	-0.66*	0.29	-0.01	$Y = -3.67 -0.44X_1 +0.04X_2 +0.16X_3 -0.37X_4 +0.07X_5$	0.145#
Nepidae	-0.30	-0.30	-0.33	-0.30	0.34	0.33	$Y = -3.88 -0.55X_1 -0.34X_2 +0.17X_3 -0.08X_4 +0.08X_5 +0.01X_6$	0.202#
Notonectidae	-0.62*	-0.75*	-0.85*	-0.77*	0.76*	0.66*	$Y = 378.48 -18.67X_1 -14.13X_2 -6.42X_3 +1.49X_4 +0.72X_5 +0.05X_6$	0.824*
Pleidae	-0.64*	-0.61*	-0.53	-0.55	0.40	0.11	$Y = 81.85 -2.25X_1 -6.56X_2 -1.10X_3 +0.10X_4 -0.19X_5 -0.02X_6$	0.432#
Veliidae	-0.58*	-0.63*	-0.38	-0.40	0.37	-0.06	$Y = -8.14 -0.49X_1 -2.91X_2 +0.33X_3 +0.01X_4 +0.07X_5 -0.01X_6$	0.386#

*—Significant at $p<0.05$ | #—Not significant | X_1—water pH | X_2—Electrical conductivity (EC) | X_3—Air temperature (AT) | X_4—Water temperature (WT) | X_5—Relative humidity (RH) | X_6—Rainfall (RF) | R^2—coefficient of determination.

to other aquatic hemipterans. Streams & Newfield (1972) reported the winter populations of Notonectidae with high distributions among a large number of water bodies in which there was a continuous stagnation of water in England. The second eudominant family Corixidae had the highest abundance during study period. Savage (1989), reported that Corixidae is the pioneer in quickly colonizing new habitats, including newly transplanted rice fields. This might be the possible reason for the population establishment in the rice crop. Purkayastha & Gupta (2015), reported that *Micronecta scutellaris* (Stål, 1858) belonging to the family Corixidae was eudominant (37.29%) during winter in a flood plain ecosystem of Assam. Bao et al. (2021) observed that the family Corixidae was the most abundant hemipteran in the rice fields of Uruguay. The above studies are in conformity with the present findings. In our findings, the optimal water level in the rice fields maintained with the support of Mettur dam water and abundant rain, resembles a permanent wetland habitat in kharif and rabi season, respectively. Therefore, the rice fields serve as suitable habitats for aquatic hemipterans.

CONCLUSION

These aquatic hemipterans are economically significant to the rice ecosystem because they are predators of rice predators like the Brown Planthopper *Nilaparvata lugens* (Stål) and Green Leafhopper *Nephotettix* spp. From this observation, we conclude that physicochemical characteristics and weather parameters directly influence the distribution pattern of aquatic hemipterans in rice fields. Although the application of agro-chemicals and other regular operations significantly reduce the biodiversity, these rice fields serve as a temporary wetland in the absence of natural wetlands, providing habitat for the conservation of several aquatic hemipteran species as well as other macro-invertebrates.

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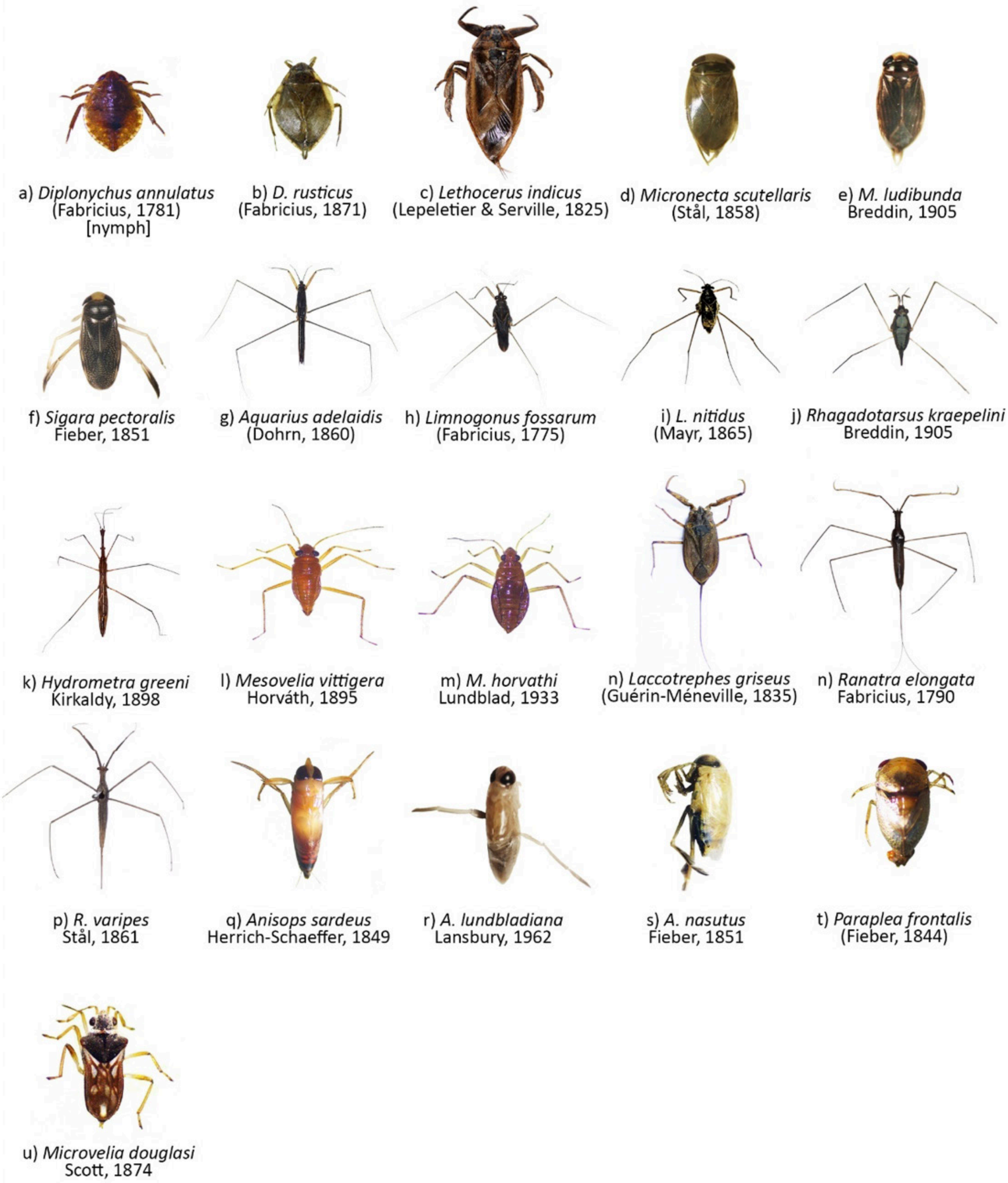

Image 1. Aquatic hemipterans collected from rice fields of Karaikal, Puducherry, India. © L Gopianand.

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