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Productivity of *Culex tritaeniorhynchus* in Rice Fields of West Bengal, India: Correlates of Immature and Adult Features

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Abstract

Background: Surveillance of larval habitats is a part of entomological monitoring to determine the abundance and facilitate vector mosquito management.

Objective: Survey of the rice field habitats was carried out to characterize the productivity of *Culex tritaeniorhynchus* Giles, 1901 (Diptera: Culicidae), in West Bengal, India. Apart from the numerical abundance, the life history traits of the mosquito were assessed to enhance the information on the fitness of the individuals.

Methods: Mosquito immature were collected following repeated sampling of rice fields during the paddy rice cultivation. The pupal weight (PW), adult body weight (AW) and wing length (WL) of *Cx. tritaeniorhynchus* and co-occurring mosquitoes were subjected to multivariate statistical analysis and ANOVA. Correlates of environmental factors, abundance and life history traits were validated as predictors of *Cx. tritaeniorhynchus* productivity.

Results: Four different mosquitoes namely *Culex quinquefasciatus*, *Anopheles annularis*, *An. subpictus* and *An. vagus* were encountered in varied number along with *Cx. tritaenorhynchus*, which could be discriminated significantly using the PW, AW and WL as variables. Water depth ($r = +0.349$) and plant height ($r = -0.423$) appeared to be a significant ($P < 0.05$) predictor of the productivity of the mosquito *Cx. tritaeniorhynchus*. Variations in the correlated traits PW, AW and WL of *Cx. tritaeniorhynchus* corresponded to the time period of paddy rice cultivation substantiated through the ANOVA.

Conclusion: The pupal productivity as well as the correlated traits PW, AW and WL of *Cx. tritaeniorhynchus* varied with the time period of paddy rice cultivations, paddy plant height and water depth. The correlated variations with productivity calls for inclusion of the life history traits in entomological monitoring of *Cx. tritaeniorhynchus* to appraise the fitness and the population abundance with higher precision.

Keywords

Culex tritaeniorhynchus; Japanese encephalitis; Pupal weight; Body weight; Wing length; Rice fields

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Introduction

Rice fields are breeding ground of numerous species of mosquitoes that are associated with disease transmission affecting health of human and domestic animals [1,2]. The vector of Japanese encephalitis, *Culex tritaeniorhynchus* Giles, 1901 (Diptera: Culicidae) prefers to breed in rice field habitats, evident from the studies around the world [3,4]. Entomological monitoring of the mosquito species is being employed to provide information about the population abundance and prediction of the prospect of the disease at a spatio-temporal scale. Thus, entomological surveillance on the mosquito *Cx. tritaeniorhynchus* is carried out in areas where Japanese encephalitis is common [5,6]. The abundance of *Cx. tritaeniorhynchus* in the rice fields corresponds to the prevalence of Japanese encephalitis, both in northern [1,7] and southern [1] India. Observation in rice fields of West Bengal, India, indicates the presence of *Cx. tritaeniorhynchus* in the rice fields along with other vector mosquitoes [8]. In Indian context, however, information on the productivity and the life history traits of *Cx. tritaeniorhynchus* from the breeding sites are little known, in comparison to the adult population [6] and the Japanese encephalitis virus they transmit [9,10]. Thus the present study was aimed at assessment of the productivity as well as the life history traits of *Cx. tritaeniorhynchus* from rice fields was made using Burdwan, West Bengal, India as a focal geographical area.

Entomological monitoring of the rice fields for *Cx. tritaeniorhynchus in* different parts of the world [11-16] emphasize the numerical abundance of the mosquito, though the fitness aspects of the mosquitoes remain undermined. Life history traits like pupal weight and the adult body size serve as good indicators of the efficacy of transmission of disease by mosquitoes [17-19]. In insects including mosquitoes the appraisal of the pupal weight and the adult features are essential to predict the fitness of the individuals constituting the population. Thus inclusion of the life history traits in mosquito assessment programs provides better information to characterize the prevalence and the fitness of the concerned mosquito species, evident from the studies on the dengue vectors in Thailand [20]. Therefore to predict the fitness of the individuals thriving in the rice fields, the pupal weight and the adult dry weight and wing length of the *Cx. tritaeniorhynchus was* carried out. The pupal weight is an indicator of the larval effort towards the development of a competent adult with increased weight as a positive contributor to the fitness. The resource acquisition by the larval stages through feeding is crucial for the development into a successful pupa and subsequent adult stages [17-23]. Since the pupa is a non-feeding stage the resource accumulated by the larva is reflected through the pupal weight. Thus pupal weight can be used as a surrogate of the resources acquired during the larval development that enables emergence of a fit adult [17-19]. Using the correlates of the pupal weight, adult body weight and wing length, as a measure of the larval development in the rice fields, the fitness of *Cx. tritaeniorhynchus* can be deduced. The results of the present study will substantiate this proposition and its significance in the entomological surveillance program. Comparative assessment using the parameters will enable understanding the life history strategies and variations in the mosquitoes breeding in the rice field habitats.

Materials and Methods

Study area

The mosquito immature were sampled from the rice fields and allied habitats of the University Farm House, Tarabag (23°15'7" N, 87°50'35" E), The University of Burdwan, Burdwan, India, and few rice fields in adjacent district of Hooghly, (Khanyan, 23°03'6"N, 88°30'8" E) West Bengal, India. During the paddy rice cultivation periods in the rainy and the winter seasons between 2010, 2012 and 2013 sampling was done. Selected sites of the rice fields were considered as sampling sites during the wet conditions of the rice paddy cultivation period.

Sampling method

The collections of mosquitoes were made [24,25] at regular interval from the rice fields during the wet conditions, following transplantation of paddy plants. Collections were restricted to wet conditions since in the dry conditions the rice field proper lacked water and thus the mosquito immature and other aquatic macro invertebrates. The sampling was conducted first week onward following transplantation of the paddy plants in the rice fields. Random sampling of selected rice plots of the University Farm House at Tarabag, Burdwan, and Khanyan, Hooghly was continued for the *boro* cultivation (February –March) of 2012 and 2013. Random stratified sampling was employed following standard protocols [24,26], to collect mosquito immature from selected rice fields. An insect net (200µm mesh size) fitted to an iron frame (20cm X 15 cm) with long handle was dredged in the inundated rice fields covering 1m^{2}area, chosen randomly. At least nine samples were considered for a rice field of 1 ha area. The net trapped organisms and debris were emptied in a plastic bag and brought to the laboratory for identification and counting. In the laboratory, the plastic bags were emptied in enamel tray (46 X 32 X 6cm) containing tap water and the mosquito larvae and pupae were counted and separated and further placed in separate vials to emerge as adults. The larval stages were identified according to proper keys [27]. Prior to placement into the glass vials, individual pupa were weighed to the nearest 0.1 mg in a pan balance and the vials were marked with the date and the weight. Following emergence the adults were killed through starvation and the dead adults were allowed to dry naturally. The adults were further weighed and recorded. The wing length of individual adult was measured underneath a bionocular fitted with ocular micrometer (Erma®, Japan) and the data were recorded to the nearest 0.1mm. In each sampling day irrespective of the mosquito species the data on the pupal weight (PW, in mg), adult weight (AW, in mg) and the wing length (WL, in mm) were recorded. The emerged adults were identified up to the species level following suitable key [13,28-31].

Data analysis

A Discriminant Function Analysis (DA) [32,33] was performed to classify the different mosquito species based on the pupal weight, wing length and the adult weight as explanatory variables. The purpose of the discriminant function analysis was to portray the differences in the life history traits of the mosquito occurring in the same habitat conditions. The Fisher's distance was used as an estimate to denote the differences among the species and sex of the mosquitoes. Using the time (period of paddy rice cultivation) and the sex as the source of variations, the differences in the pupal weight, adult body weight and wing length of *Cx. tritaeniorhnchus* were judged through 2-way ANOVA. Correlations among the immature productivity of *Cx. tritaeniorhynchus* and the selected environmental parameters including paddy plant height and water depth were carried out. The data on the pupal weight, wing length and the adult weight of the mosquito *Cx. tritaeniorhynchus were* subjected regression analysis [34], to justify the correspondence among the life history traits, for both the sexes separately. For each trait, a degree of sexual dimorphism [18] was estimated and subjected to one-tailed t-test to justify the differences in the sexes with reference to that trait. Since the collections were made at different time interval and the individuals were considered at random, each of the data represented a true replicate following the norms of interspersion and randomization [35].

Results

The five mosquito species namely *Culex quinquefasciatus* Say, 1823, *Cx. tritaeniorhynchus* , *Anopheles annularis* van der Wulp, 1884, *An. subpictus* Grassi, 1899 and *An. vagus* Donitz, 1902 were observed in varied number from the samples of the rice fields . A total 67 samples were taken from 9 different weeks including Golapbag, Burdwan (42 samples) and Khanyan, Hooghly, (25 samples) West Bengal, India. The concerned rice fields remained inundated for different time period, which limited continuous sampling of the mosquito larvae from the rice fields. However, the time span of the sampling included nine different sampling weeks in parity with the paddy rice cultivation in these areas. In course of sampling the plant height (5.5 – 63.1cm, mean 42.88 ± 19.15 cm SE) and the water depth (3.5 – 41cm, mean 16.96 ± 18.9 cm SE), varied considerably as were the total mosquito immature in each sample (2 – 347individuals, mean 103.97 ± 69.3 SE). The water quality were characterized through, conductivity (921 - 2400 µs, mean 1412.318 ± 260.14 µs SE), salinity (453 – 1220ppm, mean 700 ± 134.21 ppm SE), Total dissolved solids (TDS; 653 – 1680ppm, mean 1000.83 ± 182.38 ppm SE), pH (8.8 – 10.5, mean 9.58 ± 0.34SE) and the temperature (27.4 – 36.3˚C, mean 33.03 ± 2.7 ˚C SE). The luminosity of the rice fields during the sampling period remained on average 546×10^5 ± 185.54 lux (range 254×10^5 to 803×10^5 lux).). A total of 436 pupa collected from the samples successfully emerged as adults that could be identified to the species level [13,28-31]. Corresponding variations in the pupal weight, adult weight and wing length were observed for the male and female mosquitoes (Figure 1), which are further reflected through the discriminant function analysis (DA). Using the pupal weight, adult weight and wing length as explanatory variables, the mosquitoes could be separated on the basis of species and sex (Figure 2). Significant differences between the mosquito *Cx. tritaeniorhynchus* with other species were observed reflected through the Fisher's distance. Comparison among other mosquito species was restricted due to the low sample size for the respective species (Figure 2), though the dominance of *Cx. tritaeniorhynchus* was observed in the samples. The correlations matrix of the environmental variables and the total larval count is shown in Table 1. The plant height was significantly negatively correlated while the water height was positively correlated for the total count of immature. However, the data were discrete in term of the various rice fields sampled thereby restricting the assessment of the effects of the environmental variables as a regulator of the productivity of the mosquitoes.

The time scale dependent variation in the pupal weight, adult weight and the wing length was observed for *Cx. tritaeniorhynchus* (Figure 3). The results of ANOVA indicated significant differences in the life history traits corresponding to the time of sampling

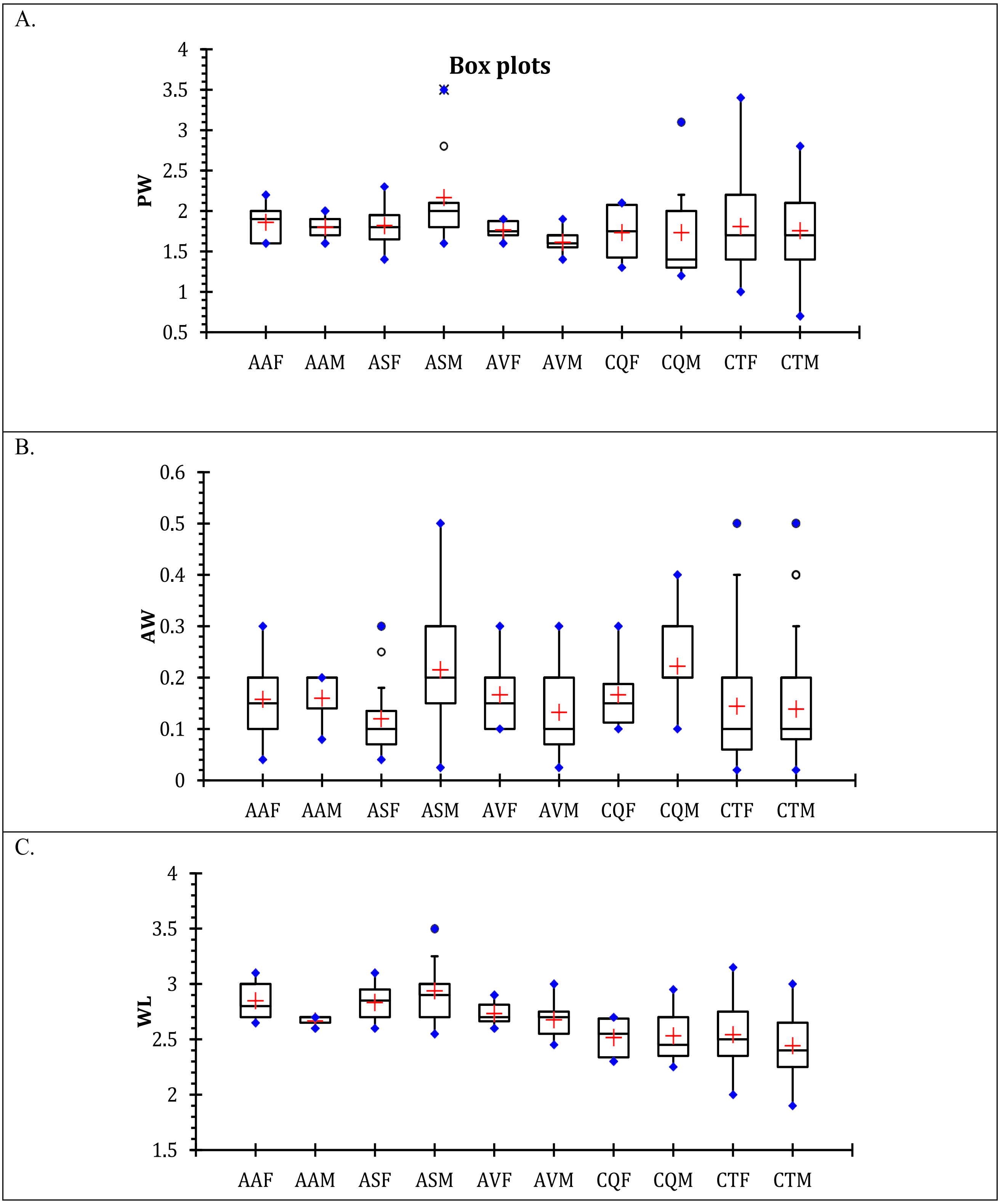
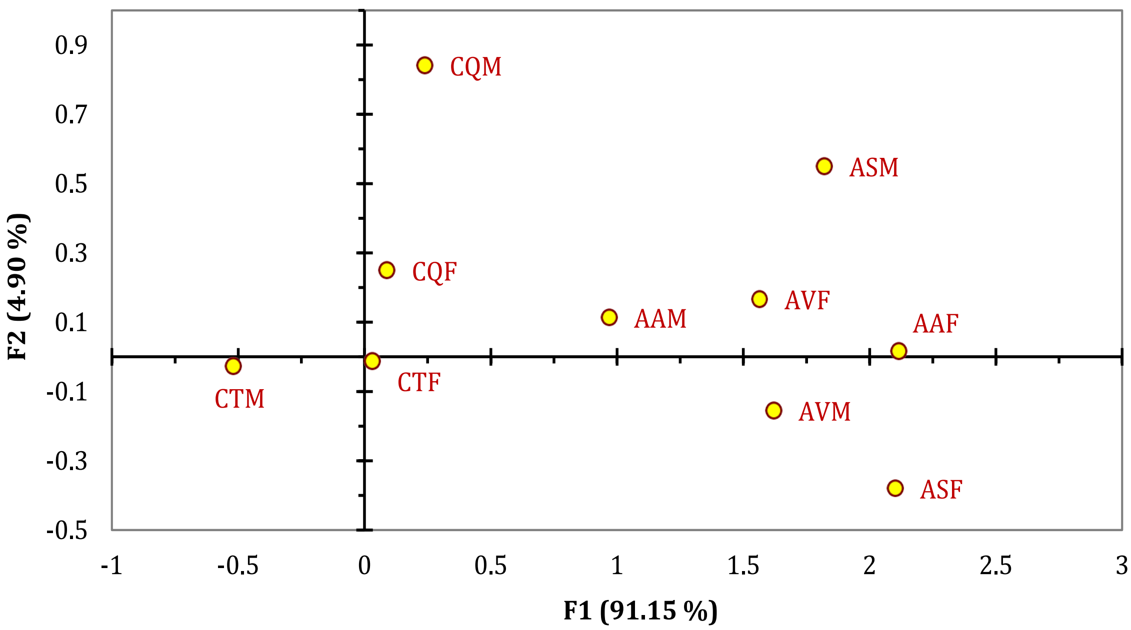


Figure 1: Box plot representing –[A] the pupal weight (PW), [B] adult dry weight (AW) and [C] wing length (WL) of the mosquito species encountered in the rice fields in Burdwan, India. Among the mosquitoes, *Cx. tritaeniorhynchus* (CT; n= 373), remained dominant with relative low representation *of Cx. quinquefasciatus* (CQ; n= 15), *An. vagus* (AV; n= 21), *An. annularis* (AA; n= 18), and *An. subpictus* (AS; n=24). F- Female and M- male**.**

	F1	F2	F3
Eigenvalue	0.525	0.028	0.023
Discrimination (%)	91.154	4.900	3.945
Cumulative %	91.154	96.055	100.000
Canonical correlations	0.587	0.166	0.149

	F1	F2	F3
P W	-1.375	-0.068	1.180
A W	0.050	1.050	-0.359
W L	1.736	-0.085	-0.096



	AAF	AAM	ASF	ASM	AVF	AVM	CQF	CQM	CTF
AAM	0.830								
ASF	0.198	1.281							
ASM	0.767	1.036	2.330						
AVF	0.347	0.251	0.943	1.075					
AVM	0.665	0.553	1.445	**3.257**	0.255				
CQF	**3.821**	0.540	**6.436**	**4.519**	2.176	**3.669**			
CQM	**4.701**	0.888	**9.706**	**5.488**	**2.698**	**5.418**	0.498		
CTF	**7.021**	0.894	**20.327**	**10.889**	**4.739**	**13.062**	0.286	**2.871**	
CTM	**11.252**	2.196	**32.422**	**17.768**	**8.543**	**22.264**	0.937	**4.268**	**9.773**

Figure 2: The results of the discriminant function analysis to segregate the mosquitoes on the basis of species and sex using pupal weight (PW) adult weight (AW) and wing length (WL) as explanatory variables. Among the mosquitoes, *Cx. tritaeniorhynchus* (CT), remained dominant with relative low representation of *Cx. quinquefasciatus*(CQ), *An. vagus*(AV), *An. annularis*(AA), and *An. subpictus* (AS). F- Female and M- Male. The Wilk's λ value was 0.624; $F_{27, 1274} = 8.281$; P<0.0001.

Table 1: Correlation matrix for the environmental variables and the mosquito productivity in the rice field samples from West Bengal, India. (Water depth in cm, WD; Paddy plant height in cm, PH; Total dissolved solids TDS)

Variables	Immature Abundance	WH (cm)	PH (cm)	Conductivity (µS)	TDS (ppm)	Salinity (ppm)
WD(cm)	**0.349**					
PH (cm)	**-0.423**	**-0.897**				
Conductivity(µS)	**-0.251**	-0.075	0.115			
TDS (ppm)	**-0.251**	-0.077	0.117			
Salinity(ppm)	**-0.237**	-0.057	0.095	**0.929**	**0.929**	
Temp(°C)	0.120	0.118	-0.072	**0.290**	**0.289**	**0.245**

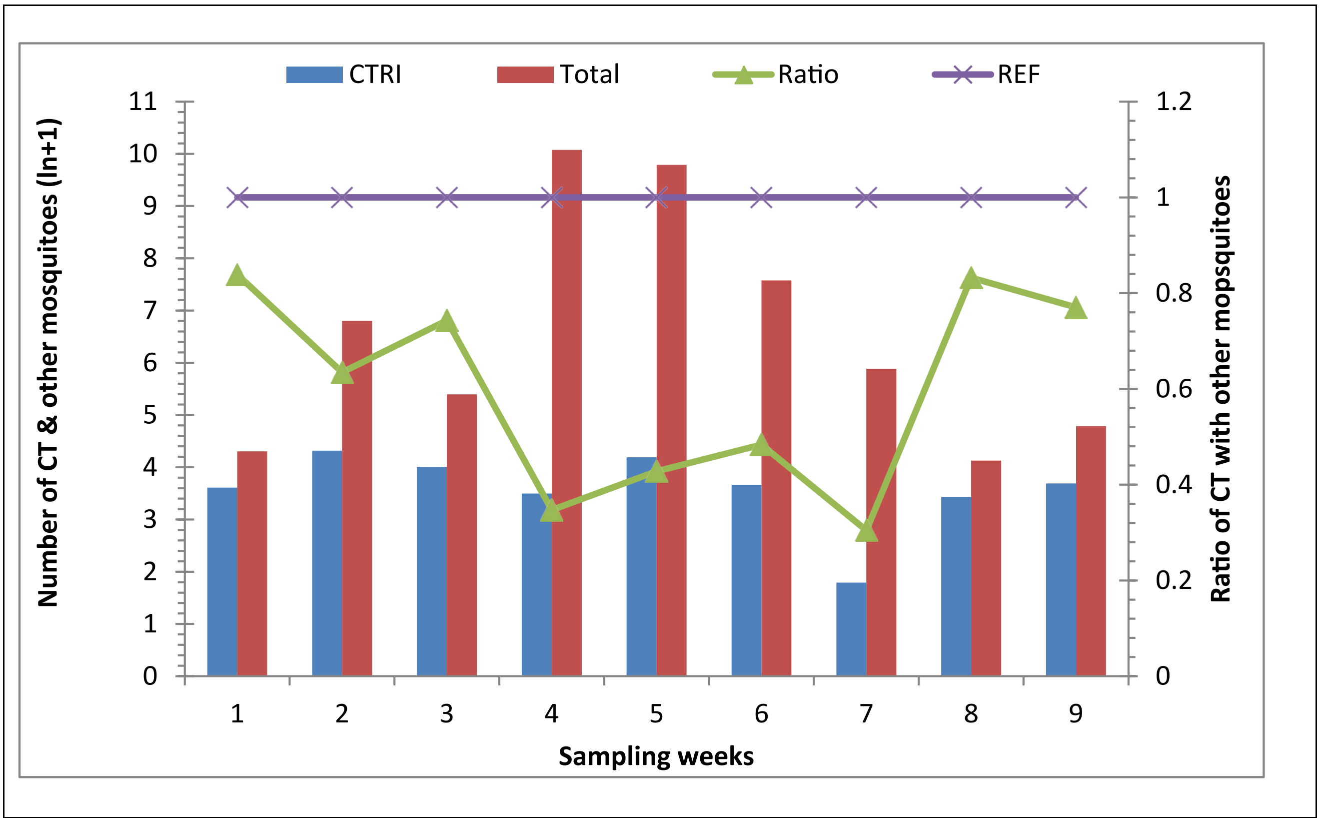


Figure 3: The proportion of *Cx. tritaeniorhynchus* against the total number of mosquito emerging from the collected immature in the sampling weeks from West Bengal, India. The reference line (dashed line) indicates the ratio of abundance of *Cx. tritaeniorhynchus* and other mosquitoes, if they are equal to unity.

(weeks) and the sex (Table 2). Positive correlations among the life history traits viz., pupal weight, adult weight and wing length were observed reflected in linear regressions (Figure 4), for both sexes of *Cx. tritaeniorhynchus.* For all the three life history traits, the degree of sexual dimorphism was significantly inclined towards the female of *Cx. tritaeniorhynchus* (Figure 5).

Discussion

Rice fields are congenial breeding sites for vector mosquitoes [12,14-16]. Empirical evidences suggest that different Anopheline and Culicine species are abundant in the rice fields of Sri Lanka [36,37], Korea [38-40], Indonesia [41,42], Philippines [43], Japan [14,44], China [45], Malaysia [46], Greece [16], Vietnam [15], Mali [47] and Kenya [12,48], and to a lesser extent in the rice fields of Australia [49] and Portugal [50]. Among the Culicine mosquitoes, *Cx. tritaeniorhynchus* , the vector of Japanese encephalitis, breed in the rice fields, as evident from the JE endemic countries like Japan [14,44], India [51,52] and several other tropical countries [12,14-16,36-38,40-44,46-48]. In Indian context, the relative abundance of *Cx. tritaeniorhynchus is* observed in the rice fields, in both Southern and Northern regions [51-54]. As observed in the present study, the mosquito *Cx. tritaeniorhynchus remained* a dominant species in the rice field habitats. Apart from the numerical abundance the pupal weight, wing length and adult weight of *Cx. tritaeniorhynchus and* the co-occurring mosquitoes remained sufficiently different to segregate and discriminate the mosquito population in terms of species and sex (Figure 2). However, the species diversity of the mosquitoes were low compared to other places [15,16]. The pattern of diversity of mosquitoes in rice fields varies with a suite of conditions including geographic, environmental and paddy rice cultivation pattern. Perhaps a combination of different factors including sampling error and the dry and wet regime of the rice fields may have contributed to the low species diversity of mosquitoes.

Table 2: The results of the univariate ANOVA using the time and sex as explanatory variables for the observations on pupal weight, adult weight and wing length of *Cx. tritaeniorhynchus.*

Source of variation	Pupal weight		Adult weight		Wing length	
	df	F	df	F	df	F
Time	8	**150.403**	8	**8.644**	8	**16.884**
Sex	1	**9.311**	1	**4.698**	1	**8.343**
Time * Sex	8	**2.581**	8	1.458	8	0.462
Error	359		358		359	
Total	376		375		376	

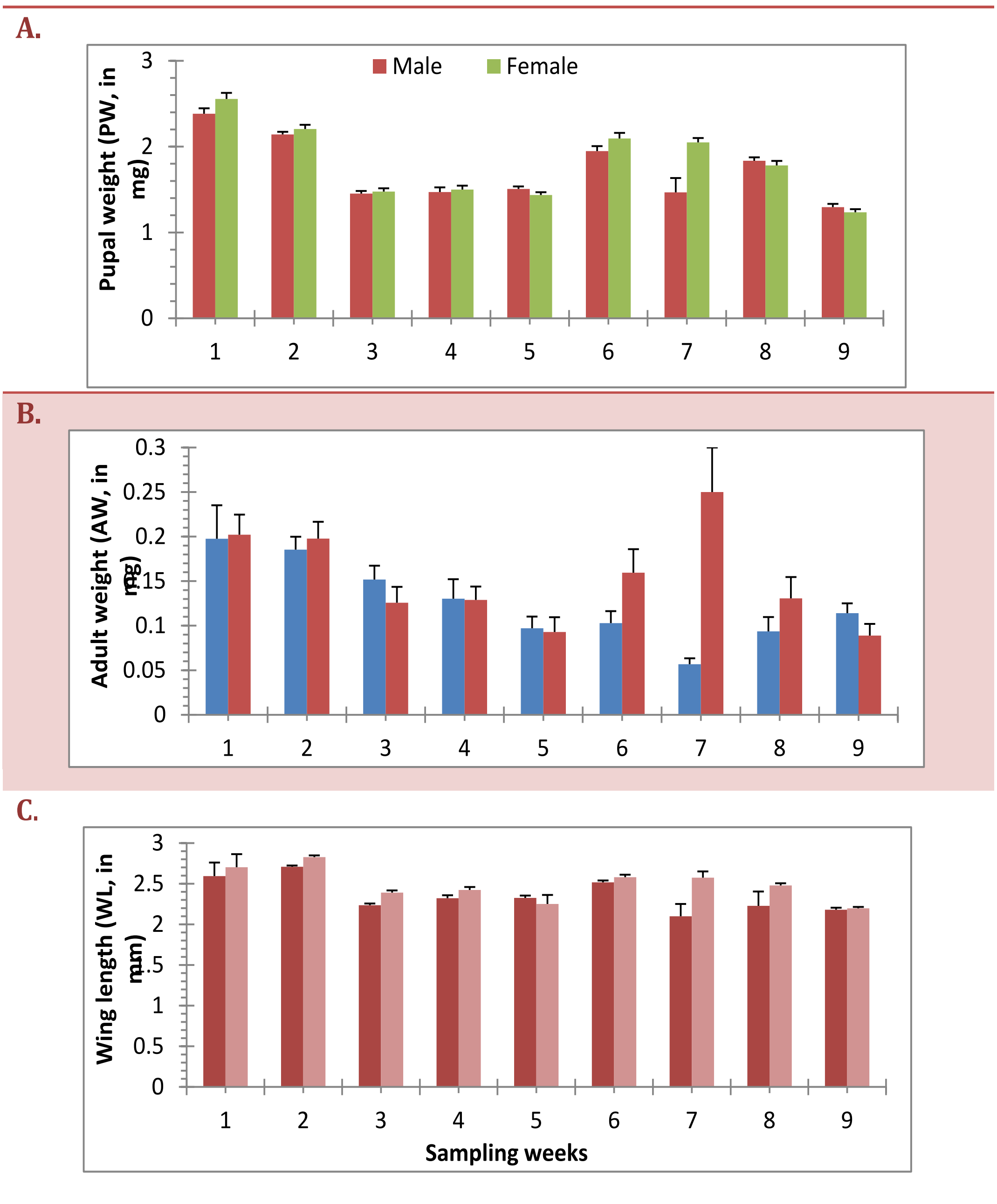


Figure 4: The life history traits (pupal weight, PW in mg, in A; adult dry weight, AW in mg, in B; and wing length, WL in mm, in C) of *Cx. tritaeniorhynchus* sampled from rice fields for nine consecutive weeks post transplantation. The univariate ANOVA applied on the data of pupal weight (PW), adult weight (AW) and wing length (WL) using the time period and sex as explanatory variables. (n= 373 individuals).

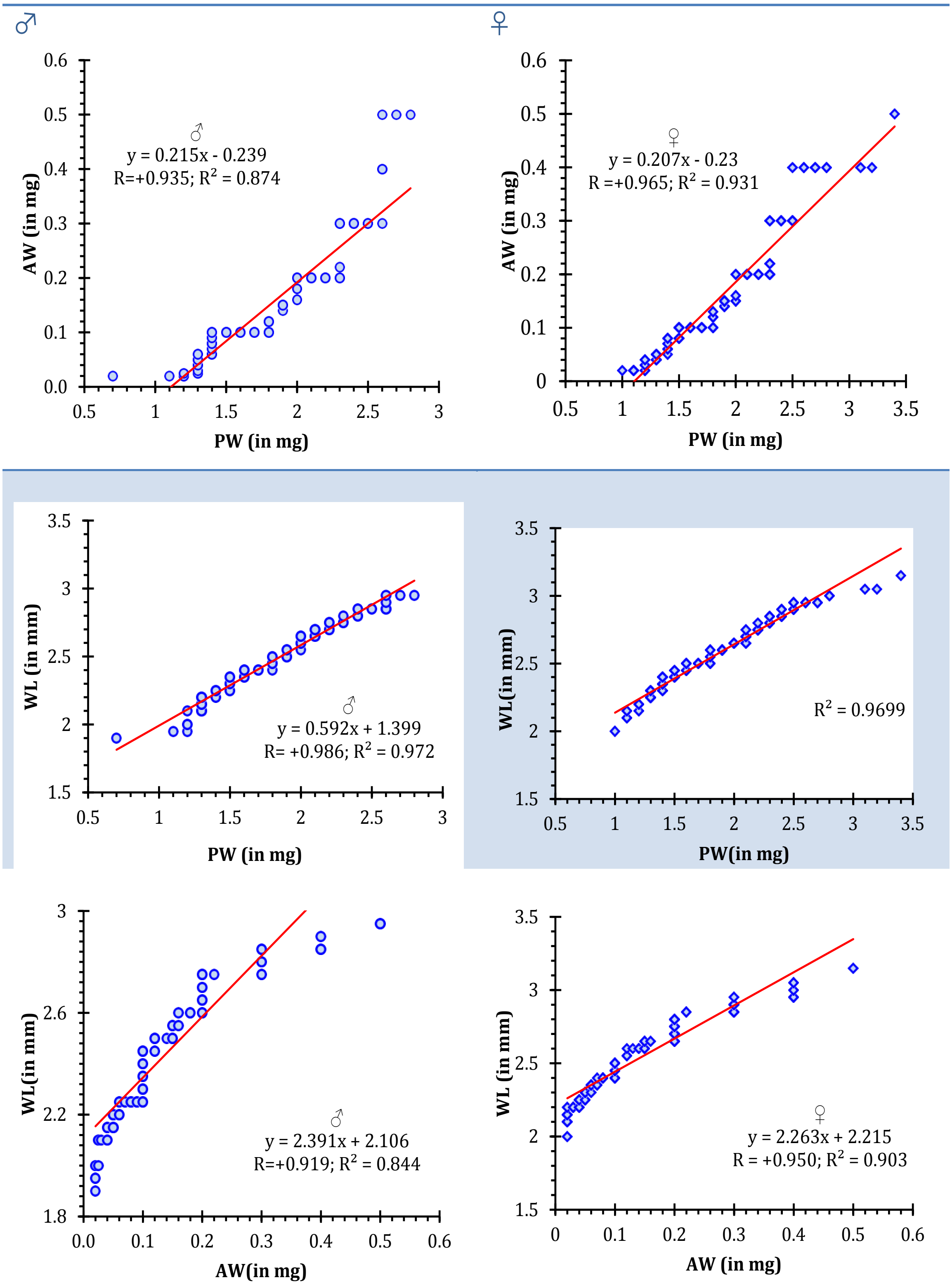


Figure 5: The regression equations depicting the relationship among the three life history traits, pupal weight (PW), adult dry weight (AW) and wing length (WL) in male (♂) and female (♀) *Cx. tritaeniorhynchus* (♂ = 177; ♀ =194).

The habitat conditions in the rice fields change temporally, that is reflected in the water depth and the paddy plant height. Whereas the paddy plants may increase in height with the time period of the cultivation, the water logged conditions and thus the water depth may vary with time. Owing to the alternative dry and wet conditions the rice fields vary in habitat permanence which may influence the colonization pattern and development pattern of the mosquitoes. As a result the productivity of the mosquitoes may vary in the time scale of paddy rice cultivation, but show a positive relation with the water depth and a negative relationship with the paddy plant height [1,7,14,15,51,53]. Similarly, a positive correlation between number of immature and water depth and a negative correlation between plant height and the immature was observed in the present instance. A negative correlation results between the paddy plant height and the water depth in the rice fields over the time period of cultivation. Thus the paddy plant height and the water depth may serve as indicators to predict the productivity of *Cx. tritaeniorhynchus.* Similar observations have been made for other mosquito species of the rice fields where the productivity varied with the time period of the paddy cultivation [46,54].

The numerical dominance of adult *Cx. tritaeniorhynchus* among other vectors has been attributed to the sampling design and differences in biting activity, host preference and host-seeking strategy [55,56]. For the present observations, the prospective reasons for the dominance can be attributed to the phenology of the co-occurring mosquitoes and the conditions of the oviposition habitat sites [46-48]. Owing to the intermittent water logged condition, the rice fields vary in terms of tenure and quality as mosquito larval habitat. As a consequence, the larval resource acquisition may have varied resulting in corresponding variations in the pupal weight, adult body weight and wing length of the mosquito *Cx. tritaeniorhynchus.* Thus, in the rice field habitats, the productivity of *Cx. tritaeniorhynchus* is not limited to the variations in the numerical abundance, as observed in earlier studies [1,4,7,42,53], but also varies in terms of the life history traits over the period of paddy rice cultivation. The correspondence of the pupal weight with the adult body weight and wing length indicate that the pupal size can be used as an indicator to predict the prospective adult size, and consequently the efficacy of disease transmission. The relation of adult body size and disease transmission (wing length and body weight) is established for the dengue vectors [19,20] (Figure 6). Although, similar direct observations are lacking for Japanese encephalitis, the estimate of the life history traits coupled with the productivity may enhance the information retrieved through monitoring of *Cx. tritaeniorhynchus* in rice field habitats. While the adult emergence pattern of the mosquito may be relevant to understand the prospective population abundance, the body weight and the wing length features would indicate the variation in the transmission efficiency of Japanese encephalitis virus. However, this opinion needs to be substantiated through empirical studies on the virus and *Cx. tritaeniorhynchus interaction* using the morphometric features as the explanatory variables.

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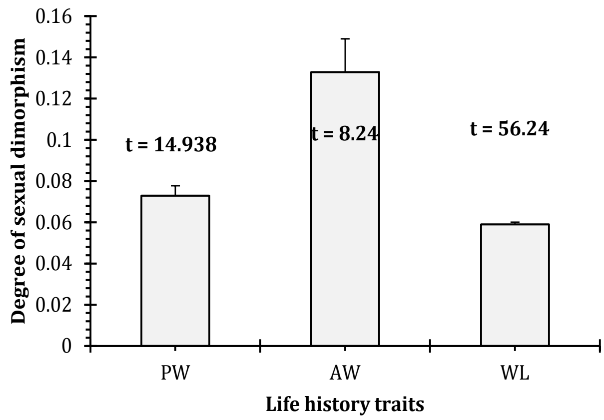

Figure 6: The degree of sexual dimorphism for the mosquito *Cx. tritaeniorhynchus* against the pupal weight (PW), adult weight (AW) and wing length (WL) as life history traits (values of 142 paired ♂ and ♀ individuals. The t-values in bold indicate significance at $P < 0.05$ level.

References

1. Sunish IP, Reuben R (2002) Factors influencing the abundance of Japanese encephalitis vectors in ricefields in India--II. Biotic. Med Vet Entomol 16: 1-9.
2. Dale PER, Knight JM (2008) Wetland and Mosquitoes: a review. Wetland Ecol Manage 16: 255-276.
3. Self LS, Shin HK, Kim KH, Lee KW, Chow CY, et al. (1973) Ecological studies on Culex tritaeniorhynchus as a vector of Japanese encephalitis. Bull World Health Organ 49: 41-47.
4. Ohba SY, Takagi M (2010) Predatory ability of adult diving beetles on the Japanese encephalitis vector Culex tritaeniorhynchus. J Am Mosq Control Assoc 26: 32-36.
5. Okuno T, Tseng PT, Liu SY, Hsu SY, Huang CT (1971) Rates of infection with Japanese encephalitis virus of two culicine species of mosquito in Taiwan. Bull World Health Organ 44: 599-604.
6. Ramesh D, Muniaraj M, Samuel P, Thenmozhi V, Venkatesh A, et al (2015) Seasonal abundance & role of predominant Japanese encephalitis vectors Culex tritaeniorhynchus & Cx. gelidus Theobald in Cuddalore district, Tamil Nadu. Indian J Med Res 142: 23-29.
7. Kanojia PC (2007) Ecological study on mosquito vectors of Japanese encephalitis virus in Bellary district, Karnataka. Indian J Med Res 126: 152-157.
8. Pramanik MK, Aditya G, Raut SK (2006) A survey of anopheline mosquitoes and malarial parasite in commuters in a rural and an urban area in West Bengal, India. J Vector Borne Dis 43: 198-202.
9. Sarkar A, Banik A, Pathak BK, Mukhopadhyay SK, Chatterjee S (2013) Envelope protein gene based molecular characterization of Japanese encephalitis virus clinical isolates from West Bengal, India: a comparative approach with respect to SA14-14-2 live attenuated vaccine strain. BMC Infect Dis 13:368
10. Sarkar A, Datta S, Pathak BK, Mukhopadhyay SK, Chatterjee S (2015) Japanese encephalitis associated acute encephalitis syndrome cases in West Bengal, India: A sero-molecular evaluation in relation to clinico-pathological spectrum. J Med Virol 87: 1258-1267.
11. Das BP, Shiv Lal, Saxena VK (2004) Outdoor resting preference of Culex tritaeniorhynchus, the vector of Japanese encephalitis in Warangal and Karim Nagar districts, Andhra Pradesh. Indian J Med Res 41: 32–36.
12. Chandlar JA, Highton RB (1975) The succession of mosquito species (Diptera: Culicidae) in rice fields in the Kisumu area of Kenya, and their possible control. Bull Entomol Res 65: 295-302.
13. Das BP (2013) Mosquito vectors of Japanese encephalitis virus from northern India. The role of BPD hop cage method. Springer, India.
14. Ohba SY, Matsuo T, Takagi M (2013) Mosquitoes and other aquatic insects in fallow field biotopes and rice paddy fields. Med Vet Entomol 27: 96-103.

15. Ohba SY, Van Soai N, Van Anh DT, Nguyen YT, Takagi M (2015) Study of mosquito fauna in rice ecosystems around Hanoi, northern Vietnam. Acta Trop 142: 89-95.

16. Lytra I, Emmanouel N (2014) Study of Culex tritaeniorhynchus and species composition of mosquitoes in a rice field in Greece. Acta Trop 134: 66-71.

17. Banerjee S, Aditya G, Saha GK (2013) Pupal productivity of dengue vectors in Kolkata, India: implications for vector management. Indian J Med Res 137: 549-559.

18. Banerjee S, Mohan S, Saha N, Mohanty SP, Saha GK, et al. (2015) Pupal productivity & nutrient reserves of Aedes mosquitoes breeding in sewage drains & other habitats of Kolkata, India: Implications for habitat expansion & vector management. Indian J Med Res 142: 87-94.

19. Mohan S, Banerjee S, Mohanty SP, Saha GK, Aditya G (2014) Assessment of pupal productivity of Aedes and co-occurring mosquitoes in Kolkata, India. Southeast Asian J Trop Med Public Health 45: 1279-1291.

20. Strickman D, Kittayapong P (2003) Dengue and its vectors in Thailand: calculated transmission risk from total pupal counts of Aedes aegypti and association of wing-length measurements with aspects of the larval habitat. Am J Trop Med Hyg 68: 209-217.

21. Agnew P, Haussy C, Michalakis Y (2000) Effects of density and larval competition on selected life history traits of Culex pipiens quinquefasciatus (Diptera: Culicidae). J Med Entomol 37: 732-735.

22. Agnew P, Hide M, Sidobre C, Michalakis YA (2002) Minimalist approach to the density -dependent competition on insect life-history traits. Ecol Entomol 27: 396-402.

23. Briegel H (2003) Physiological bases of mosquito ecology. J Vector Ecol 28: 1-11.

24. WHO (2003) Malaria entomology and vector control. Learner’s guide. Geneva. Switzerland

25. Silver JB (2008) Mosquito ecology: field sampling methods. Springer, New York, USA.

26. Robert V, Le Goff G, Ariey F, Duchemin JB (2002) A possible alternative method for collecting mosquito larvae in rice fields. Malar J 1: 4.

27. Rattanarithikul R, Harbach RE, Harrison BA, Panthusiri P, Jones JW, et al. (2005) Illustrated keys to the mosquitoes of Thailand. II. Genera Culex and Lutzia. Southeast Asian J Trop Med Public Health 36 Suppl 2: 1-97.

28. Sirivanakaran S (1970) Current study of genus Culex in Southeast Asia (Diptera: Culicidae). Mosq Syst 2: 48-52.

29. Sirivanakaran S (1975) The systematics of Culex vishnui complex in Southeast Asia with the diagnosis of three common species (Diptera: Culicidae). Mosq Syst 7: 69-85.

30. Reuben R, Tewari SC, Hiriyan J, Akiyama J. (1994) Illustrated keys to species Culex (Culex) associated with Japanese Encephalitis in Southeast Asia (Diptera: Culicidae). Mosq Systemat 26: 75-96.

31. Nagpal BN, Srivastava A, Saxena R, Ansari MA, Dash AP, et al (2005) Pictorial identification key for Indian Anophelines. Malaria Research Centre (ICMR), New Delhi, India,

32. Legendre P, Legendre I (1998) Numerical ecology. (2nd edn), Amsterdam, Netherlands, Elsevier Science.

33. Manly BFJ (1994) Multivariate analysis: a primer. Chapman and Hall,London, UK.

34. Zar JH (1999) Biostatistical Analysis. (4th edn), Pearson Education Singapore Pvt. Ltd New Delhi, India.

35. Cardamone M, Puri NK (1992) Spectrofluorimetric assessment of the surface hydrophobicity of proteins. Biochem J 282 : 589-593.

36. Klinkenberg E, van der Hoek W, Amerasinghe FP (2004) A malaria risk analysis in an irrigated area in Sri Lanka. Acta Trop 89: 215-225.

37. Yasuoka J, Levins R (2007) Ecology of vector mosquitoes in Sri Lanka--suggestions for future mosquito control in rice ecosystems. Southeast Asian J Trop Med Public Health 38: 646-657.

38. Kim HC, Lee JH, Yang KH, Yu HS (2002) Biological control of Anopheles sinensis with native fish predators (Aplocheilus and Aphyocypris) and herbivorous fish, Tilapia in natural rice fields in Korea. Korean J Entomol 32: 247-250.

39. Kim HC, Rueda LM, Wilkerson RC, Foley DH, Sames WJ, et al. (2011) Distribution and larval habitats of Anopheles species in northern Gyeonggi Province, Republic of Korea. J Vector Ecol 36: 124-134.

40. Richards EE, Masuoka P, Brett-Major D, Smith M, Klein TA, et al. (2010) The relationship between mosquito abundance and rice field density in the Republic of Korea. Int J Health Geogr 9: 32.

41. Mogi M, Memah V, Miyagi I, Toma T, Sembel DT (1995) Mosquito (Diptera: Culicidae) and predator abundance in irrigated and rain-fed rice fields in north Sulawesi, Indonesia. J Med Entomol 32: 361-367.

42. Stoops CA, Gionar YR, Shinta, Sismadi P, Rusmiarto S, et al. (2008) Larval collection records of Culex species (Diptera: Culicidae) with an emphasis on Japanese encephalitis vectors in rice fields in Sukabumi, West Java, Indonesia. J Vector Ecol 33: 216-217.

43. Mogi M, Miyagi I (1990) Colonization of rice fields by mosquitoes (Diptera: Culicidae) and larvivorous predators in asynchronous rice cultivation areas in the Philippines. J Med Entomol 27: 530-536.

44. Mogi M (1984) Mosquito problems and their solution in relation to paddy rice production. Protect Ecol 7: 219-240.

45. Wiwatanaratanabutr I, Zhang C (2016) Wolbachia infections in mosquitoes and their predators inhabiting rice field communities in Thailand and China. Acta Trop 159: 153-160.

46. Abu Hassan A, Hamady D, Tomomitsu S, Michael B, Jameel S L AS (2010) Breeding patterns of the JE vector Culex gelidus and its insect predators in rice cultivation areas of northern peninsular Malaysia. Trop Biomed 27: 404-416.

47. Klinkenberg E, Takken W, Huibers F, Touré YT (2003) The phenology of malaria mosquitoes in irrigated rice fields in Mali. Acta Trop 85: 71-82.

48. Muturi EJ, Shililu JI, Jacob BG, Mwangangi JM, Mbogo CM, et al. (2008) Diversity of riceland mosquitoes and factors affecting their occurrence and distribution in Mwea, Kenya. J Am Mosq Control Assoc 24: 349-358.

49. Wilson AL, Watts RJ, Stevens MM (2007) Effects of different management regimes on aquatic macroinvertebrate diversity in Australian rice fields. Ecol Res 23: 565 – 572.

50. Leitão S, Pinto P, Pereira T, Brito MF (2007) Spatial and temporal variability of macroinvertebrate communities in two farmed Mediterranean rice fields. Aquat Ecol 41: 373-386.

51. Kant R, Pandey SD, Sharma RC (1992) Seasonal prevalence and succession of rice field breeding mosquitoes of central Gujarat. J Commun Dis 24: 164-172.

52. Kant R, Pandey SD, Sharma SK, Sharma VP (1998) Species diversity and interspecific associations among mosquitoes in rice agro-ecosystem of Kheda district, Gujarat. Indian J Malariol 35: 22-30.

53. Victor TJ, Reuben R (1999) Population dynamics of mosquito immatures and the succession in abundance of aquatic insects in rice fields in Madurai, South India. Indian J Malariol 36: 19-32.

54. Sunish IP, Reuben R, Rajendran R (2006) Natural survivorship of immature stages of Culex vishnui (Diptera: Culicidae) complex, vectors of Japanese encephalitis virus, in rice fields in southern India. J Med Entomol 43: 185-191.

55. Lord JS, Al-Amin HM, Chakma S, Alam MS, Gurley ES, et al (2016) Sampling design influences the observed dominance of Culex tritaeniorhynchus: Considerations for future studies of Japanese encephalitis virus transmission. PLoS Neg Trop Dis 10: 0004249.

56. Juliano SA, Ribeiro GS, Maciel-de-Freitas R, Castro MG, Codeço C, et al. (2014) She’s a femme fatale: low-density larval development produces good disease vectors. Mem Inst Oswaldo Cruz 109: 1070-1077.

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