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Observations on the Mosquitoes (*Diptera: Culicidae*) of Udawattakele Forest, Sri Lanka

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Abstract: Thirty-six species of mosquitoes were recorded during a field study at the Udawattakele Forest Reserve, Kandy, Sri Lanka. Immatures of 17 species were collected from breeding sites (bamboo stumps, kitul-palm stumps, tree holes, temporary ground pools), the highest occurrences being for *Culex* (*Lophoceraomyia*) *uniformis* (Theobald), *Aedes* (*Stegomyia*) *krombeini* Huang, *Aedes* (*Stegomyia*) *albopictus* (Skuse) and *Toxorhynchites* (*Toxorhynchites*) *splendens* (Wiedemann) from the natural container habitats, and *Aedes* (*Verrallina*) *pseudomediofasciatus* (Theobald) and *Anopheles* (*Cellia*) *elegans* (James) from ground pools. Sixty-four types of single and multi-species occurrences were recorded from breeding sites. A positive interspecific association was shown between *Ae. albopictus* and *Ae. krombeini*, and a negative association between *Ae. albopictus* and *Tx. splendens*, in the bamboo stump habitat. Twenty-one species were taken at day-time human bait catches, the most prevalent being *Ae. albopictus* and *Armigeres* (*Armigeres*) *subalbatus* (Coquillett), for which a preliminary interpretation of the biting activity levels within the forest is given. *Aedes krombeini*, a recently described member of the medically important *scutellaris* group of *Aedes* (*Stegomyia*), though breeding commonly in the area, was only rarely attracted to the human bait.

1. Introduction

One hundred and thirty one species of mosquitoes in 16 genera are known from Sri Lanka.[14] There is, however, a dearth of information relating to the biology of the majority of these species in Sri Lanka, with much of the attention, of necessity, being focussed upon those mosquitoes that are of direct medical importance. Published information relating to the Sri Lankan Culicidae, in general, are contained in works such as Barraud[1], Carter,[2,3,4] Carter and Wijesundera[5], Chow *et al*[6], Christophers[7] James,[12,13] Senior-White,[20,21] and Wijesundara.[28] More recent contributions include the publications of workers attached to the Southeast Asia Mosquito Project (SEAMP) and Medical Entomology Project (MEP) of the Smithsonian Institution, and deal mainly with bio-taxonomic aspects of the mosquito fauna of the Oriental and S-E Asian regions, including Sri Lanka.

The present paper presents some ecological observations on mosquitoes occurring in the Udawattakele Forest Reserve, Kandy, in the Central Province of Sri Lanka. Surrounded by urban areas, this small patch of isolated forest harbours many species of sylvan and peridomestic mosquitoes, which have not hitherto been studied systematically. This investigation focussed on the breeding biology and diurnal man-biting activity of these mosquitoes, aspects that are of particular interest in view of the large human population in immediate proximity to the forest, and its popularity as a human recreational area.

2. The Study Area

Approximately 254 acres (101.6 ha) in extent, Udawattakele Forest is situated on undulating terrain at an elevation of 600m above mean sea level, within the municipal limits of the town of Kandy, Central Province, Sri Lanka (latitude 7° N, longitude 81°E). The habitat is best described as a degraded secondary forest, with remnant forest flora such as *Mangifera zeylanica* (Bl.) Hook.F., *Canarium zeylanicum* (Retz.) Bl., *Diospyros sylvatica* Roxb., *Pterocarpus indicus* Willd., *Michelia champaca* L., *Artocarpus nobilis* Thw., *Myristica dactyloides* Gaertn., and *Pterospermum canescens* Roxb. A total of 46 acres (18.4 ha) was planted with species such as *Filicium decipiens* (Wight & Arn.), *Artocarpus heterophylla* Lam., *Pericopsis mooniana* (Thw.), *Mesua nagassarium* (Burm.f.) Kosterm,. *Michelia champaca* L., *Sweitenia macrophylla* King, *Alstonia macrophylla* Wall, and *Chukrasia tabularis* A. Juss, during 1922—1936, and these species now contribute significantly to the forest canopy.

The mean annual temperature of the area is 24.5°C and mean annual rainfall 2131 ± 30 mm. However, rainfall records at the Central Agricultural Research Institute, Gannoruwa (approximately 8km from the forest) show that during the 15 month period of the present study (February 1980 to April 1981 inclusive), the total precipitation was only 1849.80 mm, with rain occurring on 174 days. Low rainfall (< 100mm /month) occurred in February-March, September and December 1980, and January-February 1981. All other months received more than 100mm rain, the highest values being for November 1980 (333.4mm) and April 1980/81 (209.1 and 205.1mm respectively). These data are of relevance since rainfall is one of the major factors affecting the availability of mosquito breeding sites in the forest, and thus their density and species composition.

3. Materials And Methods

Field collections at Udawattakele Forest were carried out during February 1980 to April 1981. Monthly collections of mosquito immatures were made in a survey area of approximately 25 acres (10 ha). The main breeding habitats studied were stumps of the giant bamboo (*Dendrocalamus giganteus* Munro), stumps of the kitul palm (*Caryota urens* L.), tree holes below a height of 5m from ground level (the limitation being one of accessibility), and small temporary ground pools. The borders of a large natural pond situated in the survey area, as well as crab holes along a stream leading to it were also investigated. Approximately 400 ml of water was pippetted from each potential breeding site, after suitable agitation to break up any localised aggregations of mosquito immatures. In a few instances where less than this volume of water was available, the entire quantity was taken. The pH of the water was measured on collection, using BDH pH paper. The larvae (3rd and 4th instar) and pupae in each sample were counted and reared to the adult, usually in individual tubes.

Diurnal man-biting mosquitoes were collected by means of 15mt stationary two-man landing-biting catches at points situated 100m apart along the footpaths within the forest, under conditions of partial to dense shade at ground level. All mosquitoes landing /biting on the exposed face, arms and legs of the seated baits were collected in individual numbered tubes. One hundred and eighty such 15mt catches were done, arranged so as to total 20 catches for each hour between 0900 and 1800 hours.

The species identifications (based on adult habitus and terminalia features, and immatures where obtained) were made with reference to the descriptions and keys contained in the series of publications by taxonomists at SEAMP and MEP (Smithsonian Institution), and other relevant works[1,5,7,17,28]. Reference collections of adults have been deposited in the Entomology Division, Department of National Museums, Sri Lanka, and the British Museum (Natural History).

4. Results

4.1 Species List

A full list of the 36 species of mosquitoes collected during the study is given below, with the genera arranged according to the systematic sequence in Stone *et al*[27]. Generic and subgeneric abbreviations used later in the text follow Reinert[19]. The method of collection of each species is also indicated, i.e. immature collections from breeding sites (Br), adults from bait catches (Ba) and random hand-net catches (N):

Anopheles (Anopheles) peditaeniatus (Leicester) 1908 .... Ba
Anopheles (Anopheles) aitkenii group, Reid & Knight 1961 .... Ba/N
Anopheles (Cellia) elegans (James) 1903 .... Br
Toxorhynchites (Toxorhynchites) splendens (Wiedemann) 1819 .... Br
Tripteroides (Tripteroides) affinis (Edwards) 1913 .... Br/N
Tripteroides (Rachionotomyia) aranoides (Theobald) 1901 .... Br
Orthopodomyia anopheloides (Giles) 1903 .... Br
Heizmannia (Heizmannia) greeni (Theobald) 1905 .... Br/Ba
Heizmannia sp. .... Ba
Aedes (Finlaya) aureostriatus (Doleschall) 1857 .... Br/Ba/N
Aedes (Finlaya) gubernatoris (Giles) 1901 .... Ba
Aedes (Finlaya) pseudotaeniatus (Giles) 1901 .... Ba
Aedes (Finlaya) sp. (*niveus* subgroup) .... Br
Aedes (Christophersiomyia) annulirostris (Theobald) 1905 .... Ba
Aedes (Stegomyia) aegypti (Linnaeus) 1762 .... Ba/N
Aedes (Stegomyia) albopictus (Skuse) 1894 .... Br/Ba/N
Aedes (Stegomyia) novalbopictus Barraud 1931 .... Ba/N
Aedes (Stegomyia) krombeini Huang 1975 .... Br/Ba
Aedes (Stegomyia) mediopunctatus (Theobald) 1905 .... Br/Ba

Aedes (*Stegomyia*) *w-albus* (Theobald) 1905 .... Ba
Aedes (*Aedimorphus*) *jamesi* (Edwards) 1914 .... Ba
Aedes (*Aedimorphus*) *vittatus* (Bigot) 1861 .... Ba
Aedes (*Paraedes*) *chrysoscuto* (Theobald), ref. Reinert 1981 .... Ba/N
Aedes (*Verrallina*) *pseudomediofasciatus* (Theobald) 1910 .... Br/Ba
Armigeres (*Armigeres*) *subalbatus* (Coquillett) 1898 .... Br/Ba/N
Culex (*Lutzia*) *fuscanus* Wiedemann 1820 .... N
Culex (*Eumelanomyia*) *brevipalpis* (Giles) 1902 .... Br
Culex (*Lophoceraomyia*) *uniformis* (Theobald) 1905 .... Br/N
Culex (*Lophoceraomyia*) *lasiopalpis* Sirivanakarn 1977 .... N
Culex (*Lophoceraomyia*) *wardi* Sirivanakarn 1977 .... N
Culex (*Culiciomyia*) *nigropunctatus* Edwards 1926 .... N
Culex (*Culiciomyia*) *pallidothorax* Theobald 1905 .... N
Culex (*Culex*) *fuscocephala* Theobald 1907 .... Br/N
Culex (*Culex*) *mimulus* Edwards 1915 .... Br
Culex (*Culex*) *sitiens* group & subgroup, Edwards 1932 .... Ba
Culex (*Culex*) *pseudovishnui* Colless 1957 .... Ba/N

The specific status of bait-caught females of the *An. aitkenii* group is uncertain, since valid species identifications cannot be made on the characters of this sex alone.[17] However, a single net-caught male displayed terminalia characters similar to the species *aitkenii* (James) 1903, as described by Reid[17], and it is possible that the females too, may belong to this species.

Males of the *Aedes* (*Finlaya*) species of the *niveus* subgroup are close to *Ae. niveoides* Barraud 1934, but this identification cannot be confirmed at present. Two females of a species of *Heizmannia* taken at bait are clearly distinct in habitus and terminalia from *Hz. greeni*, the only known representative of this genus in Sri Lanka, and does not appear to belong to any of the species recognised from the Oriental and S-E Asian regions. The status of this species, as well as the occurrence of *Ae. w-albus* and *Ae. novalbopictus* in Sri Lanka will be discussed in future papers.

4.2 Survey of Breeding Habitats

(a) Species Occurrences

A total of 189 samples were taken from the 4 main breeding habitats surveyed, of which 145 (76.6%) were positive for immatures of the Culicidae. Bamboo and Kitul-palm stumps appear to be the most heavily utilized, with 84.4% (97/115) of the former and 82.6% (19/23) of the latter containing immatures. The corresponding figures for tree holes and ground pools are 60% (12/20) and 54.8% (17/31) respectively. No mosquito immatures were collected from the borders of the pond situated in the area, while 10 samples from crab holes yielded 1 positive collection containing immatures of *Cx. uniformis*.

Numerical data on the species occurring in the 4 main breeding habitats studied are presented in Table 1. *Culex uniformis* and *Ae. krombeini* appear to be the most abundant of the container-breeding species, while *Ae. pseudomediofasciatus* predominates in the ground pool habitat. *Aedes albopictus*, though almost as frequent in occurrence as *Ae. krombeini*, occurs, in much smaller numbers per sample, and may be less abundant than *krombeini* in this habitat. Among species encountered less frequently, *Tp. affinis* and *Ar. subalbatus* were noteworthy in being relatively more numerous in positive samples than the other natural container breeders.

TABLE 1. Species occurrences at Breeding Habitats

(*Note: Figures in parenthesis refer to actual numbers of immatures*)

Habitat	Bamboo Stumps	Kitul Stumps	Tree Holes	Ground Pools	All Habitats
Number of Samples	115	23	20	31	189
Number + ve for Culicidae	97	19	12	17	145
1. *Cx. uniformis*					
Number of + ve Samples	39	10	8	2	59
Mean Immatures/+ ve Sample	6.4	9.10	13.50	3.00	7.73
Median ,, ,,	44	7	13	—	5
Range ,, ,,	1-47	1-21	1-30	—	1-47
2. *Ae. krombeini*					
Number of + ve Samples	30	3	7	1	41
Mean Immatures/+ ve Sample	13.37	7.67	3.00	(2)	10.90
Median ,, ,,	4	10	1	—	3
Range ,, ,,	1-111	1-12	1-8	—	1-111
3. *Ae. albopictus*					
Number of + ve Samples	31	4	3	—	38
Mean Immatures/+ ve Sample	4.61	2.25	2.67	—	4.21
Median ,, ,,	2	1	2	—	2
Range ,, ,,	1-31	1-6	2-4	—	1-31
4. *Tx. splendens*					
Number of + ve Sample	32	3	—	—	35
Mean Immatures/+ ve Sample	1.19	1.33	—	—	1.20
Median ,, ,,	1	1	—	—	1
Range ,, ,,	1-4	1-2	—	—	1-4

Habitat	Bamboo Stumps	Kitul Stumps	Tree Holes	Ground Pools	All Habitats
5. *Ae. aureostriatus*					
Number of + ve Samples	13	12	2	—	27
Mean Immatures/+ ve Sample	2.77	2.25	1.5	—	2.44
Median ,, ,,	2	2	—	—	2
Range ,, ,,	1-11	1-6	—	—	1-11
6. *Ae. pseudomediofasciatus*					
Number of + ve Samples	2	1	—	12	15
Mean Immatures/+ ve Sample	5.00	(1)	—	16.25	13.73
Median ,, ,,	—	—	—	10	7
Range ,, ,,	—	—	—	1-65	1-65
7. *Tp. aranoides*					
Number of + ve Samples	14	—	—	—	14
Mean Immatures/+ ve Sample	11.86	—	—	—	11.86
Median ,, ,,	3	—	—	—	3
Range ,, ,,	1-68	—	—	—	1-68
8. *An. elegans*					
Number of + ve Samples	—	—	—	10	10
Mean Immatures/+ ve Sample	—	—	—	7.10	7.10
Median ,, ,,	—	—	—	6	6
Range ,, ,,	—	—	—	1-16	1-16
9. *Ae. (Fin.) sp.*					
Number of + ve Samples	2	4	2	—	8
Mean Immatures/+ ve Sample	2.00	2.00	2.00	—	2.00
Median ,, ,,	—	2	—	—	2
Range ,, ,,	—	1-3	—	—	1-3
10. *Tp. affinis*					
Number of + ve Samples	6	1	1	—	8
Mean Immatures/+ ve Sample	14.67	(9)	(3)	—	12.50
Median ,, ,,	10	—	—	—	9
Range ,, ,,	7-38	—	—	—	3-38
11. *Ar. subalbatus*					
Number of + ve Samples	6	—	—	1	7
Mean Immatures/+ ve Sample	22.67	—	—	(5)	20.14
Median ,, ,,	10	—	—	—	10
Range ,, ,,	2-66	—	—	—	2-66

Habitat	Bamboo Stumps	Kitul Stumps	Tree Holes	Ground Pools	All Habitats
12. *Hz. greeni*					
Number of + ve Samples	6	—	—	—	6
Mean Immatures/+ ve Sample	1.83	—	—	—	1.83
Median " "	2	—	—	—	2
Range " "	1-3	—	—	—	1-3
13. *Cx. fuscocephala*					
Number of + ve Samples	—	—	—	3	3
Mean Immatures/+ ve Sample	—	—	—	4.67	4.67
Median " "	—	—	—	5	5
Range " "	—	—	—	3-6	3-6
14. *Cx. mimulus*					
Number of + ve Samples	—	—	—	3	3
Mean Immatures/+ ve Sample	—	—	—	1.33	1.33
Median " "	—	—	—	1	1
Range " "	—	—	—	1-2	1-2
15. *Cx. brevipalpis*					
Number of + ve Samples	3	—	—	—	3
Mean Immature/+ ve Sample	3.00	—	—	—	3.00
Median " "	1	—	—	—	1
Range " "	1-7	—	—	—	1-7
16. *Or. anapheloides*					
Number of + ve Samples	2	—	—	—	2
Number of Immatures	(6)	—	—	—	(6)
17. *Ae. mediopunctatus*					
Number of + ve Samples	1	—	—	—	1
Number of Immatures	(5)	—	—	—	(5)

The predatory larvae of *Tx. splendens* occurred mainly in bamboo stumps, and in the majority of samples only one immature was present. Larvae of *Toxorhynchites* are well known to prey heavily on other culicid immatures, and the data from the 97 mosquito positive bamboo stump samples presents an interesting comparison: in the 32 samples containing larvae of *Tx. splendens* the mean number of other culicid immatures per sample was 3.9 (124/32), while in the 65 samples without the predator, the mean was 17.8 (1157/65). The two means are significantly different, with $t = 2.64$, $n = 95$ and $p < 0.01$, and are a probable indication of the predatory activities of this species.

Table 1 also shows the immature habitat preferences of the more frequently occurring species, with *Ae. pseudomediofasciatus* and *An. elegans* being predominantly ground breeders, and *Cx. uniformis*, *Ae. krombeini*, *Ae. albopictus*, *Tx. splendens*, *Ae. aureostriatus*, and *Tp. aranoides* mainly inhabiting natural containers. Only *Cx. uniformis* and *Ae. krombeini* were collected from all four habitats, though both seem to be predominantly container breeders.

(b) Species Associations

Sixty four types of single and multi-species occurrences were recorded, and these are set out in Table 2. Of the 145 samples positive for culicids, 65 (45%) contained single species, 43 (30%) contained two species, 23 (16%) contained three species, and 14 (9%) contained four or more species associated. The last category consisted of 11 four-species, 2 five-species and 1 six-species associations (Table 2).

TABLE 2. Species Composition at Breeding Habitats
(The figures indicate numbers of occurrence)

Habitat	Bamboo Stumps	Kitul Stumps	Tree Holes	Ground Pools	Total
Number of Samples	115	23	20	31	189
Number Positive for Culicidae	97	19	12	17	145
(a) Single Species					
1. *Ae. albopictus*	07	—	—	—	07
2. *Ae. krombeini*	04	—	01	—	05
3. *Ae. aureostriatus*	01	03	—	—	04
4. *Ae. pseudomediofasciatus*	—	—	—	06	06
5. *Hz. greeni*	01	—	—	—	01
6. *Tp. affinis*	—	01	—	—	01
7. *Tp. aranoides*	01	—	—	—	01
8. *Ar. subalbatus*	02	—	—	—	02
9. *Tx. splendens*	16	—	—	—	16
10. *An. elegans*	—	—	—	02	02
11. *Cx. uniformis*	11	04	04	—	19
12. *Or. anopheloides*	01	—	—	—	01
Total by Habitat	44	08	05	08	65

	Habitat	Bamboo Stumps	Kitul Stumps	Tree Holes	Ground Pools	Total
	(b) Two Species Associated					
13.	*Ae. albopictus* + *Ae. krombeini*	07	—	01	—	08
14.	*Ae. albopictus* + *Tx. splendens*	01	—	—	—	01
15.	*Ae. albopictus* + *Cx. uniformis*	02	—	—	—	02
16.	*Ae. krombeini* + *Ae. aureostriatus*	01	—	—	—	01
17.	*Ae. krombeini* + *Ae. (Fin.) sp.*	—	—	01	—	01
18.	*Ae. krombeini* + *Cx. uniformis*	02	01	—	—	03
19.	*Ae. aureostriatus* + *Ae. (Fin.)* sp.	01	—	—	—	01
20.	*Ae. aureostriatus* + *Tp. affinis*	01	—	—	—	01
21.	*Ae. aureostriatus* + *Tp. aranoides*	03	—	—	—	03
22.	*Ae. aureostriatus* + *Tx. splendens*	—	01	—	—	01
23.	*Ae. aureostriatus* + *Cx. uniformis*	02	03	01	—	06
24.	*Ae. aureostriatus* + *Cx. brevipalpis*	01	—	—	—	01
25.	*Ae. pseudomediofasciatus* + *Tx. splendens*	01	—	—	—	01
26.	*Ae. pseudomediofasciatus* + *An. elegans*	—	—	—	01	01
27.	*Ae. pseudomediofasciatus* + *Cx. uniformis*	—	—	—	01	01
28.	*Ae. (Fin.)*sp. + *Tx. splendens*	01	—	—	—	01
29.	*Hz. greeni* + *Tp. aranoides*	01	—	—	—	01
30.	*Tp. affinis* + *Tp. aranoides*	01	—	—	—	01
31.	*Tp. aranoides* + *Cx. uniformis*	01	—	—	—	01
32.	*Ar. subalbatus* + *An. elegans*	—	—	—	01	01
33.	*Tx. splendens* + *Cx. uniformis*	05	—	—	—	05
34.	*An. elegans* + *Cx. mimulus*	—	—	—	01	01
	Total by Habitat	31	05	03	04	43

Habitat	Bamboo Stumps	Kitul Stumps	Tree Holes	Ground Pools	Total
(c) Three Species Associated					
35. *Ae. albopictus* + *Ae. krombeini* + *Ar. subalbatus*	01	—	—	—	01
36. *Ae. albopictus* + *Ae. krombeini* + *Cx. uniformis*	03	—	01	—	04
37. *Ae. albopictus* + *Ae. krombeini* + *Tp. affinis*	01	—	01	—	02
38. *Ae. albopictus* + *Ae. aureostriatus* + *Ae. (Fin.) sp.*	—	02	—	—	02
39. *Ae. albopictus* + *Ar. subalbatus* + *Tx. splendens*	01	—	—	—	01
40. *Ae. krombeini* + *Ae. aureostriatus* + *Cx. uniformis*	—	—	01	—	01
41. *Ae. krombeini* + *Ae. (Fin.) sp.* + *Cx. uniformis*	—	—	01	—	01
42. *Ae. krombeini* + *An. elegans* + *Ae. pseudomediofasciatus*	—	—	—	01	01
43. *Ae. krombeini* + *Tx. splendens* + *Cx. uniformis*	02	—	—	—	02
44. *Ae. krombeini* + *Tx. splendens* + *Cx. brevipalpis*	01	—	—	—	01
45. *Ae. aureostriatus* + *Ae. (Fin.) sp.* + *Cx. uniformis*	—	01	—	—	01
46. *Ae. pseudomediofasciatus* + *Tx. splendens* + *Cx. uniformis*	—	01	—	—	01
47. *Ae. pseudomediofasciatus* + *An. elegans* + *Cx. fuscocephala*	—	—	—	02	02
48. *Tp. aranoides* + *Tx. splendens* + *Cx. uniformis*	01	—	—	—	01
49. *Tp. aranoides* + *Cx. uniformis* + *Or. anopheloides*	01	—	—	—	01
50. *An. elegans* + *Cx. uniformis* + *Cx. mimulus*	—	—	—	01	01
Total by Habitat	11	04	04	04	23
(d) Four or More Species Associated					
51. *Ae. albopictus* + *Ae. krombeini* + *Ae. aureostriatus* + *Ae. (Fin.) sp.*	—	01	—	—	01
52. *Ae. albopictus* + *Ae. krombeini* + *Ae. aureostriatus* + *Tp. aranoides*	01	—	—	—	01
53. *Ae. albopictus* + *Ae. krombeini* + *Ae. aureostriatus* + *Tx. splendens*	—	01	—	—	01
54. *Ae. albopictus* + *Ae. krombeini* + *Ae. aureostriatus* + *Cx. uniformis*	01	—	—	—	01

Habitat	Bamboo Stumps	Kitul Stumps	Tree Holes	Ground Pools	Total
55. *Ae. albopictus* + *Ae. krombeini* + *Hz. greeni* + *Tx. splendens*	01	—	—	—	01
56. *Ae. albopictus* + *Ae. krombeini* + *Hz. greeni* + *Cx. uniformis*	01	—	—	—	01
57. *Ae. albopictus* + *Ae. krombeini* + *Ar. subalbatus* + *Cx. uniformis*	01	—	—	—	01
58. *Ae. albopictus* + *Tx. splendens* + *Cx. uniformis* + *Cx. brevipalpis*	01	—	—	—	01
59. *Ae. krombeini* + *Tp. aranoides* + *Tx. splendens* + *Cx. uniformis*	01	—	—	—	01
60. *Ae. pseudomediofasciatus* + *An. elegans* + *Cx. fuscocephala* + *Cx. mimulus*	—	—	—	01	01
61. *Hz. greeni* + *Tp. affinis* + *Tp. aranoides* + *Cx. uniformis*	01	—	—	—	01
62. *Ae. albopictus* + *Ae. krombeini* + *Tp. aranoides* + + *Ar. subalbatus* + *Cx. uniformis*	01	—	—	—	01
63. *Ae. mediopunctatus* + *Hz. greeni* + *Tp. affinis* + *Tp. aranoides* + *Cx. uniformis*	01	—	—	—	01
64. *Ae. albopictus* + *Ae. krombeini* + *Ae. aureostriatus* + *Cx. uniformis* + *Ae. pseudomediofasciatus* + *Tp. affinis*	01	—	—	—	01
Total by Habitat	11	02	—	01	14

A summary of the joint occurrences of species (all habitats combined) is presented in Table 3. Frequent joint occurrences between some species are evident, in particular between *Cx. uniformis*, *Ae. krombeini* and *Ae. albopictus*. The degree of interspecific association for species occurring in bamboo stumps, from which a sufficient number of samples (115) were obtained to permit further analysis, was tested by means of 2x2 contingency tables and the corrected chi-square (X^2) test as given in Southwood.[26] Since the test in this form is valid only where the expected occurrences (calculated on the hypothesis of random association) are greater than 5, only the four most frequently occurring species are considered: *Cx. uniformis*, *Ae. krombeini*, *Ae. albopictus* and *Tx. splendens*. A comparative measure of the degree of association is provided by the Coefficient of Interspecific Association (C_{AB}) of Cole.[8]

TABLE 3. Summary of Joint Occurrences of Species at Breeding Habitats
(The figures indicate numbers of occurrence)

	Cx. uniformis	*Ae. krombeini*	*Ae. albopictus*	*Tp. aranoides*	*Tx. splendens*	*Ae. aureostriatus*	*Ae. pseudomediofasciatus*	*Tp. affinis*	*Hz. greeni*	*Ar. sub albatus*	*An. elegans*	*Ae. (Fin.) sp.*	*Cx. brevipalpis*	*Ae. mediopunctatus*	*Cx. mimulus*	*Cx. fuscocephala*	*Or. anopheloides*
Total occurrences	59	41	38	14	35	27	15	08	06	07	10	08	03	01	03	03	02
Occurrences Associated	40	36	31	13	19	23	09	07	05	05	08	08	03	01	03	03	01
Cx. uniformis	—	17	12	07	10	10	03	03	03	02	01	02	01	01	01	—	01
Ae. krombeini	17	—	24	03	06	07	02	03	02	03	01	03	01	—	—	—	—
Ae. albopictus	12	24	—	02	05	07	01	03	02	04	—	03	01	—	—	—	—
Tp. aranoides	07	03	02	—	01	04	—	03	03	01	—	—	—	01	—	—	01
Tx. splendens	11	06	05	02	—	02	02	—	01	01	—	01	02	—	—	—	—
Ae. aureostriatus	10	07	07	04	02	—	01	02	—	—	—	05	01	—	—	—	—
Ae. pseudomedio-fasciatus	03	02	01	—	02	01	—	01	—	—	05	—	—	—	01	03	—
Tp. affinis	03	03	03	03	—	02	01	—	02	—	—	—	—	01	—	—	—
Hz. greeni	03	02	02	03	01	—	—	02	—	—	—	—	—	01	—	—	—
Ar. subalbatus	02	03	04	01	01	—	—	—	—	—	01	—	—	—	—	—	—
An. elegans	01	01	—	—	—	—	05	—	—	01	—	—	—	—	03	03	—
Ae. (Fin.) sp.	02	03	03	—	01	05	—	—	—	—	—	—	—	—	—	—	—
Cx. brevipalpis	01	01	01	—	02	01	—	—	—	—	—	—	—	—	—	—	—
Ae. mediopunctatus	01	—	—	01	—	—	—	01	01	—	—	—	—	—	—	—	—
Cx. mimulus	01	—	—	—	—	—	01	—	—	—	03	—	—	—	—	01	—
Cx. fuscocephala	—	—	—	—	—	—	03	—	—	—	03	—	—	—	01	—	—
Or. anopheloides	01	—	—	01	—	—	—	—	—	—	—	—	—	—	—	—	—

Contingency Table[26]

Species B	Species A	
	Present	Absent
Present	a	b
Absent	c	d

a, b, c, d, refer to numbers of occurrence, and species A occurs more frequently than species B. Details of the calculation of X^2 and C_{AB} are given in Southwood.[26] The data are as follows:

Cx. uniformis + *Ae. krombeini*
a = 13, b = 17, c = 26, d = 59; X^2 = 1.09; C_{AB} = + 0.14 ± 0.11

Cx. uniformis + *Ae. albopictus*
a = 11, b = 20, c = 28, d = 56; X^2 = 0.34 x 10^{-4}; C_{AB} = 0.02 ± 0.11

Cx. uniformis + *Tx. splendens*
a = 10, b = 22, c = 29, d = 54; X^2 = 0.35; C_{AB} = —0.08 ± 0.21

Ae. albopictus + *Ae. krombeini*
a = 19, b = 12, c = 11, d = 73; X^2 = 24.84; C_{AB} = + 0.48 ± 0.09

Tx. splendens + *Ae. krombeini*
a = 5, b = 25, c = 27, d = 58; X^2 = 3.32; C_{AB} = — 0.40 ± 0.25

Tx. splendens + *Ae. albopictus*
a = 4, b = 27, c = 28, d = 56; X^2 = 5.78; C_{AB} = — 0.54 ± 0.25
(with 1 degree of freedom the 5% level of significance is shown by X^2 = 3.84)

The above data show that the associations of *Cx. uniformis* with the other three species are due to chance occurrence. A positive interspecific association is indicated between *Ae. albopictus* and *Ae. krombeini* with the latter species appearing to be the dominant partner; of the 19 joint occurrences in bamboo stumps 7 were in the absence of other culicid species and the ratio of the immatures of *krombeini/albopictus* was 2.03 (140:69); in the 12 joint occurrences in the presence of other culicids, the ratio increased to 3.64 (211:58). A negative interspecific association is shown between *Tx. splendens* and *Ae. albopictus*, and probably between the former species and *Ae. krombeini.*

(c) pH of Breeding Water

Water samples from ground pools occupied a narrow range, from pH 5.0 to 6.5, and thus no indications are forthcoming regarding the tolerance range of the species breeding in this habitat. It is interesting, however, that the 3 occurrences of *Ae. pseudomediofasciatus* (chiefly a ground breeder) in natural containers were in acidic water within this range. Samples from natural containers varied widely (pH 5.0-10.0) and most of the container breeding species occurred over a broad pH range: 5.0 - 9.0 for *Ae. albopictus, Ae. krombeini, Tx. splendens, Cx. uniformis* and *Cx. brevi palpis;* 5.0-10.0 foi *Ae. aureostriatus* and *Tp. aranoides;* 5.0-8.0 for *Ae.* (*Fin.*) sp.; 6.0-9.0 for *Ar. subalbatus.* However, *Hz. greeni* ((pH 5.0 - 6.5) and *Tp. affinis* (pH 5.0 - 7.0) were collected only from acidic or neutral water. *Orthopodomyia anopheloides* was found in two samples of alkaline water (pH 7.5 and 8.0 ıespectively) while the single occurrence of *Ae. mediopunctatus* was from acidic water (pH 5.5).

4.3 Diurnal Bait Catches

The species taken at human bait are listed in Table 4, together with the numbers caught and percentages of the total catch. *Aedes albopictus* and *Ar. subalbatus* were the most prevalent man-biters, but five other species were also collected regularly at these catches (*Ae. chrysoscuta, Ae. aureostriatus, Ae. novalbopictus, Ae. w-albus* and *Hz. greeni*) though comprising much smaller percentages of the overall catch. This could be a reflection not only of host attractivity, but also of the abundance levels and diel biting rhythms of these species.

TABLE 4. Mosquito Species Collected at Human Bait Catches

Species	Females	
	Number Caught	Percentage of Total Catch
Ae. albopictus	576	40.65
Ar. subalbatus	353	24.91
Ae. chrysoscuta	124	8.75
Ae. aureostriatus	100	7.05
Ae. novalbopictus	98	6.98
Ae. w-albus	58	4.18
Hz. greeni	58	4.18
Cx. pseudovishnn	16	1.13
Ae. krombeini	10	0.71
An. aitkenii gp.	08	0.56
Ae. mediopunctatus	04	< 0.5
Ae. annulirostris	03	"
Heizmannia sp.	02	"
Ae. vittatus	01	"
Ae. pseudotaeniatus	01	"
Ae. gubernatoris	01	"
Ae. pseudomediofasciatus	01	"
Ae. jamesi	01	"
Cx. sitiens gp.	01	"
An. peditaeniatus	01	"
Ae. aegypti (No females; 02 males collected settled on baits)		

The technique used in the bait catches, though not designed directly to study diurnal biting rhythms, and suffering from certain limitations in this regard (see Service[22]), provides indications of major periods of biting activity during the time span investigated. With equal numbers of catches ranging over the same catch points being done per 1 hour period, it is possible to provide a preliminary interpretation of the activity patterns of the two most common man-biters in the forest, *Ae. albopictus* and *Ar. subalbatus* (Table 5). In both species, biting occurred throughout the period 0900 - 1800 hours, under the conditions of partial to dense shade within the forest, but the major period of activity seems to occur earlier in *Ae. albopictus* (with the peak period occurring in late afternoon and declining towards sunset) than in *Ar. subalbatus* (where the biting activity increases towards sunset).

TABLE 5. Percentage Catch of *Aedes albopictus* and *Armigeres subalbatus* Between 0900 - 1800 Hours at Human Bait Catches.

Local Time	0900-0959	1000-1059	1100-1159	1200-1259	1300-1359	1400-1459	1500-1559	1600-1659	1700-1759
Ae. albopictus	3.8	3.6	3.8	1.9	9.2	18.0	26.7	18.2	14.6
Ar. subalbatus	9.4	10.9	7.4	5.7	9.1	11.3	12.2	12.5	21.5

5. Discussion

Both sylvan and peridomestic mosquitoes were encountered in Udawattakele Forest. Species such as *An. elegans*, *An. aitkenii* gp., *Ae. chrysoscuta*, *Ae. pseudomediofasciatus*, *Ae. aureostriatus*, *Hz. greeni*, *Tp. affinis*, *Tp. aranoides*, *Cx. uniformis*, *Cx. wardi*, *Cx. lasiopalpis*, *Cx. mimulus* and *Cx. brevipalpis* are generally regarded as being mainly forest-dwelling in habit.[1,9,17,18,23,24,25] Species commonly associated with human habitations are *Ae. aegypti*, *Ae. albopictus*, and *Ar. subalbatus*, as well as others such as *An. peditaeniatus*, *Cx. fuscocephala* and *Cx. pseudovishnui*[9,24]. Of the potential vector species, only *Ae. albopictus* appears to be relatively abundant in the forest, being collected regularly from breeding sites and bait catches.

Apart from the apparently endemic *Ae. krombeini* (and possibly the *Ae.* (*Fin.*)sp.), the species found breeding in the forest also occur in other areas of the Oriental and S-E Asian regions. The data in Tables 2 and 3 contribute to the body of information on immature species associations in relation to habitat types, that are of interest both in a local context (where there is a paucity of published data) and in the wider context of the overall distributional range of these species. Of particular interest are the associations of *Ae. krombeini*, *Hz. greeni*, *Ae. mediopunctatus*, *Ae. pseudomediofasciatus*, *Tp. affinis*, *Tp. aranoides*, and *An. elegans*, for which little published information exists.

The positive interspecific association between *Ae. albopictus* and *Ae. krombeini* in bamboo stumps indicates the requirement of similar conditions in these two species, since other possibilities such as a predator-prey relationship or mutualism[26] can be excluded in this case. *Ae. krombeini* appears to be the more successful competitor of the two, both in the presence and absence of other culicid immatures. It is interesting that Huang[11] too mentions the frequent association of these two species in immature collections from Sri Lanka (including Udawattakele Forest).

The negative interspecific association between *Tx. splendens* and *Ae. albopictus* (and possibly *Ae. krombeini*) could be due to non-occurrence in the same sites because of differing environmental requirements or tolerances. The bamboo stumps all occurred under shade, and thus differences of light and temperature are not likely to be important in this regard. Both *Tx. splendens* and *Ae. albopictus* are tolerant of a similar pH range. Though a close examination of the data reveals that *Ae.*

albopictus shows 78% of its occurrences in bamboo from acidic water (pH 5.0 - 6.5) and 21% occurrences from alkaline water (pH 7.0 - 8.5), compared to 57% and 39% respectively for *Tx. splendens*, this is probably not an important factor in the regular non-occurrence of these two species in the same sites. A factor that does appear to contribute to such a situation is the quality of the water: approximately 33% of the occurrences of *Tx. splendens* in bamboo were from foul or turbid water, while not a single immature of *Ae. albopictus* was collected from such samples, whether from bamboo, kitul-palm or tree holes. Another possibility that must be considered here is predation by *Tx. splendens* larvae on immatures of *Ae. albopictus*, particularly if the latter is a preferred prey species. Larvae of *Tx. splendens* appear to be non-specific, feeding on immatures of several mosquito species in the laboratory (personal observations), but their prey preferences are unknown. A situation where the predator eliminates a preferred prey species before switching to other acceptable prey cannot entirely be ruled out, especially in the small container habitat (bamboo stumps) in question. Further studies will be necessary before the nature of this negative association can be clarified.

Apart from the *Heizmannia* sp. *Ae. chrysoscuta* and *Ae. novalbopictus*, all the others taken at bait have been recorded previously in the literature as biting humans. However, with the exceptions of *Ae. aegypti* and *Ae. albopictus*, they appear to be mainly zoophilic in their host preferences. The highly anthropophilic *Ae. aegypti* does not seem to be common within the forest (no breeding occurrences, and only 2 males attracted to human bait), though it occurs in the urban areas adjacent to the forest (personal observations). However, *Ae. albopictus* occurred commonly within the forest, and was the chief diurnal man-biting species collected.

One of the significant findings of the present study concerns *Ae. krombeini*, a recently described[11] member of the medically important *scutellaris* group of *Aedes* (*Stegomyia*). This species comprised an insignificant part of the total catch (0.71%) compared to several other *Stegomyia* species, in particular, *Ae. albopictus* (40.65%). The survey of breeding habitats indicated that *krombeini* is probably more abundant than *albopictus* in this area, and thus its low incidence at human bait shows that it is either a primarily zoophilic species not greatly attracted to humans or a mainly nocturnally active mosquito (or both).

An interesting feature of the catches was the regular attraction of males of *Ae. albopictus* to the human bait. A total of 141 males of this species were captured during the series of catches, while settled upon bait, but much greater numbers than actually caught were present, usually hovering around the catchers. Copulation in flight was observed at nearly every occasion that males were present. The host has been shown to be a focal point for mating in species such as *Ae. sierrensis*[15], *Ae. varipalpus*[16], and probably *Ae. aegypti*[10], and it is possible that the same phenomenon occurs in *Ae. albopictus* as well.

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