RELATIVE ABUNDANCE AND BLOOD FEEDING BEHAVIOR OF NOCTURNALLY ACTIVE CULICINE MOSQUITOES IN WESTERN KENYA

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ABSTRACT. At 2 sites in western Kenya targeted for future malaria vaccine trials, adult culicine mosquitoes were sampled over one year by 5 collection techniques to assess human exposure to potential vectors of pathogens other than malaria. Collections included 20,910 females representing 19 species in Kisian and 4,312 females of 11 species in Saradidi. Common species in Kisian included *Culex quinquefasciatus* (71.4%), *Mansonia uniformis* (15.8%), *Ma. africana* (6.2%), *Aedes mcintoshi* (2.0%), *Coquillettidia fuscopennata* (1.9%) and *Ae. ochraceus* (1.8%). Common species in Saradidi included *Cx. quinquefasciatus* (92.7%), *Cx. nebulosus* (4.5%) and *Ma. uniformis* (1.0%). Human-bait collections identified 16 man-biting culicine species in Kisian and 9 in Saradidi. Man-biting rates at Kisian for the 5 most common species were 1.8, 14.6 and 13.5 times higher than at Saradidi for indoor, outdoor and tent collections, respectively. Exposure indoors was estimated to be 1,277 bites/man/year at Kisian and 720 at Saradidi. Blood meal identification for 1,083 mosquitoes confirmed that the common culicine species feed primarily on humans and cows.

INTRODUCTION

Culicine mosquito populations on the Kano Plain in western Kenya have been studied extensively to determine the effects of irrigation on mosquito production and abundance (Surtees 1970, Surtees et al. 1970, Khamala 1971, Chandler and Highton 1975, Chandler et al. 1975b, 1976a, 1976b) and arbovirus epidemiology (Bowden et al. 1973, Johnson et al. 1977a, 1977b, 1981). The vector potential of mosquitoes in this area was evaluated further by blood meal identification (Boreman et al. 1975, Chandler et al. 1975a).

This study compared the species composition, relative abundance and blood feeding patterns of culicine mosquitoes at 2 sites, west of Kisumu, in western Kenya. Proposed malaria vaccine trials involving nonindigenous volunteers at these 2 sites necessitate the evaluation of the potential for transmission of diseases other than malaria. This study provides baseline information on culicine mosquito populations and evaluates the potential for human feeding among the common species collected by 5 sampling methods.

MATERIALS AND METHODS

Adult culicine mosquitoes were sampled over a year, beginning in February 1987, in the villages of Kisian (10 km west of Kisumu) and Saradidi (55 km west of Kisumu), western Kenya. Study sites, collection techniques and meteorological sampling were described in detail for concurrent studies on anophelines (Beier et al. 1990). Briefly, Kisian is located on the shores of Lake Victoria where extensive papyrus swamp provides year-round larval development sites. During the rainy seasons, larval development also occurs in temporary ground water pools and containers. At Saradidi, a site with typical savanna-type vegetation, larval development occurs in temporary and permanent ground water pools along streams, pit latrines and containers.

Weekly all-night human-bait collections at each site were conducted with pairs of collectors, working in 0.5-h periods from sunset to sunrise, inside 6 houses, 2 outdoor stations and in one army general purpose medium tent (Beier et al. 1990). Resting mosquitoes inside houses were collected by aspiration from over 50 houses per week at each site; additionally, pyrethrum spray catches (World Health Organization 1975) were done in 12 houses per week in Kisian. Six CDC light traps at each site were operated outdoors each week on the night of human-bait collections. Twenty outdoor aspiration collections (0700–0930 h), using a mechanical aspirator, were done in Kisian from September to December 1987. Mosquitoes attracted to a tethered cow in a an outdoor bednet trap (2 × 1 × 2 mm; elevated 15–20 cm) were aspirated at 2-h intervals during weekly all-night collections in Kisian, and from September to December 1987 in Saradidi.

Culicine mosquitoes from each collection were killed, placed in vials, frozen at −20°C and transported to Nairobi for identification, using the taxonomic keys of Edwards (1941) and other descriptions (van Someren 1949, Huang 1985).

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The number of mosquitoes for each species was related to sampling effort for the 5 collecting techniques. For human-bait collections, abundance was expressed as the number of females/man/night. Man-biting rates inside houses, outdoors and in tents were transformed to $\log_{10}(n + 1)$ to normalize variance, and were examined by analysis of variance (ANOVA) and the Fisher PLSD test to evaluate differences in biting rates among types of sampling sites. Overall mean man-biting rates are presented as Williams' mean values (M_w) (Williams 1937), calculated as back-transformed values of the monthly mean.

Blood-fed mosquitoes from each collection were later air-dried at room temperature for up to 5 days, and placed individually in labeled vials. Each mosquito was ground in 50-µl PBS, with 950-µl PBS added after grinding; these were stored frozen at −70°C. Blood meals were identified by a direct enzyme-linked immunosorbent assay (ELISA) using anti-host (IgG) conjugates (Kirkegaard and Perry, Gaithersburg, MD) against human, cow, donkey, goat, dog, cat, rat, rabbit and chicken (Beier et al. 1988). Blood meals were screened first for human and cow, then nonreacting samples were tested for the other 7 hosts.

RESULTS

Sampling during 12 months yielded 20,910 adult females representing 19 culicine species in Kisian, and 4,312 females consisting of 11 species in Saradidi (Table 1). Common species in Kisian, representing 99.1% of the total collected, included *Culex quinquefasciatus*, *Mansonia uniformis*, *Ma. africana*, *Aedes mcintoshi*, *Coquillettidia fuscopennata* and *Ae. ochraceus*. In Saradidi, *Cx. quinquefasciatus*, *Cx. nebulosus* and *Ma. uniformis* comprised 98.2% of the total. Additionally, 7,680 males of 14 species were collected in Kisian and 2,033 males of 4 species were collected in Saradidi; males of species collected at each site are noted in Table 1. Over 90% of the males were *Cx. quinquefasciatus*. Males were collected primarily in CDC light traps, pyrethrum spray catches and by aspiration in vegetation.

There were 16 species collected in human-bait collections in Kisian compared with 9 in Saradidi (Table 1). Fewer species were detected by the other collection techniques. In indoor resting collections, *Culex quinquefasciatus* comprised about 98% of 6 species collected at Kisian and 8 species at Saradidi. Cow-baited traps yielded 14 species at Kisian and 4 species at Saradidi. Light traps collected 10 species at Kisian and 6 species at Saradidi. Aspiration collections in vegetation yielded 7 species at Kisian, but this method was not used at Saradidi.

Average man-biting rates for 5 species, representing over 95% of the total mosquitoes obtained in human-bait collections, were compared for indoor, outdoor and tent collections (Table 2). Inside houses, highest biting rates were observed for *Cx. quinquefasciatus*. In Kisian, biting rates for *Cx. quinquefasciatus* inside houses were significantly higher than outdoors or in tents. Biting rates for *Ae. mcintoshi*, *Cq. fuscopennata*, *Ma. africana* and *Ma. uniformis* were highest outdoors. In Saradidi, differences in man-biting rates among collection techniques were detected only for *Cx. quinquefasciatus*. Overall man-biting rates in Saradidi for these 5 species were 1.8, 14.6 and 13.5 times lower than in Kisian for indoor, outdoor and tent collections, respectively.

Monthly average man-biting rates were examined in relation to rainfall for *Cx. quinquefasciatus*, *Ma. africana* and *Ma. uniformis* at Kisian (Fig. 1) and for *Cx. quinquefasciatus* at Saradidi (Fig. 2).

Blood meals were identified by ELISA for 88.3% of 1,226 specimens tested (Table 3). *Culex quinquefasciatus*, representing 97.9% (1,054/1,077) of the specimens tested from indoor resting collections, fed primarily on humans (87.6%); outdoors, most of the blood meals were identified as cow (61.3%) and human (22.7%). Blood meals from both *Mansonia* species were primarily human and cow. *Aedes mcintoshi* and *Cq. fuscopennata* fed mainly on cows. Two chicken blood meals were detected in *Cx. nebulosus*; avian feeding was also observed for *Cq. fuscopennata*, *Cx. quinquefasciatus* and *Ma. africana*. Mixed blood meals for *Cx. quinquefasciatus* included 25 human and cow, 5 chicken and cat, and outdoors, one goat and rabbit meal. Mixed human and cow meals were also detected for one *Ae. mcintoshi* and 3 *Ma. uniformis*. One cat-rabbit mixed blood meal was identified for *Cq. fuscopennata*.

DISCUSSION

The species composition of culicine mosquitoes from the 2 sites west of Kisumu was similar to previous reports from the Kano Plain, east of Kisumu (Surtees 1970, Chandler et al. 1975b, 1976b). Culicine species diversity and relative abundance at Kisian were considerably higher than at Saradidi. Kisian has extensive permanent larval development sites, including papyrus swamp, due to its location on the shore of Lake Victoria. The savanna habitat of Saradidi appears to support fewer species as a result of reduced larval habitat diversity. The 21 species

Table 1. Adult female culicine species relative abundance, in Kisian and Saradidi study sites, western Kenya (February 1987 to January 1988).

Mosquito species	% of total females		No. females/collection technique[1]								
			Kisian					Saradidi			
	Kisian	Saradidi	B	R	C	L	V	B	R	C	L
Aedes aegypti formosus (Walker)[2]	<0.1	<0.1	12				1	1	1		
Aedes africanus (Theobald)	<0.1	<0.1	11		1				1		
Aedes chaussieri Edwards	<0.1	0.0	1								
Aedes hirsutus (Theobald)	<0.1	0.0	5								
Aedes mcintoshi Huang[2]	2.0	0.1	275	1	26	6	103	1		4	1
Aedes metallicus (Edwards)	<0.1	0.0	3		2						
Aedes mucidus (Karsch)[2]	<0.1	0.0	9		2	1					
Aedes ochraceus (Theobald)[2]	1.8	0.1	291		66	10		5			1
Aedes quasiunivittatus (Theobald)[2]	0.1	0.0	16		4						
Aedes vitattus (Bigot)	0.0	<0.1							3		
Coquillettidia fuscopennata (Theobald)[2,3]	1.9	0.7	142	1	171	30	62	8	1	21	
Culex annulioris Theobald	0.0	<0.1						1			
Culex nebulosus Theobald[2,3]	0.4	4.5		8	13	49	12	54	13	1	126
Culex quinquefasciatus Say[2,3]	71.4	92.7	2,176	3,823	8,377	110	436	912	3,060	19	6
Culex theileri Theobald[2]	<0.1	0.0	2								
Culex tigripes Degrandpre & DeCharmoy[2]	<0.1	0.0			12	3					
Culex univittatus Theobald group[2]	<0.1	0.0	10		1						
Eretmapodites chrysogaster Graham	<0.1	0.0	9								
Mansonia africana (Theobald)[2]	6.2	0.7	971	39	190	85	21	15	10		5
Mansonia uniformis (Theobald)[2,3]	15.8	1.0	2,743	32	290	192	42	22	18		2
Mimomyia plumosa (Theobald)[2]	<0.1	0.0			6	6					
Total	20,910	4,312	6,676	3,904	9,161	492	677	1,019	3,107	45	141

[1] B = human-bait, R = indoor resting collection, C = cow-baited trap, L = light trap outdoors, V = aspiration in vegetation.
[2] Males collected in Kisian.
[3] Males collected in Saradidi.

Table 2. Man-biting rates of 5 common mosquito species collected during all-night biting collections inside houses, outdoors and in tents at Kisian and Saradidi sites, western Kenya (February 1987 to January 1988).

Mosquito species	Abundance (M_W)[1]					
	Kisian			Saradidi		
	Indoors (258)[2]	Outdoors (82)	Tent (69)	Indoors (204)	Outdoors (70)	Tent (62)
Aedes mcintoshi	0.05a	1.54b	0.24a	0.00a	0.05a	0.00a
Coquillettidia fuscopennata	0.06a	0.48b	0.23c	0.04a	0.00a	0.00a
Culex quinquefasciatus	2.25a	1.14b	0.25c	1.86a	0.92a/b	0.33b
Mansonia africana	0.31a	2.03b	1.64b	0.03a	0.01a	0.02a
Mansonia uniformis	0.83a	9.12b	3.71c	0.04a	0.00a	0.10a

[1] Williams' mean number of mosquitoes per man-night. For each species in each site, means followed by the same letter are not significantly different ($P > 0.05$) (Fisher PLSD).
[2] Number of man-nights.

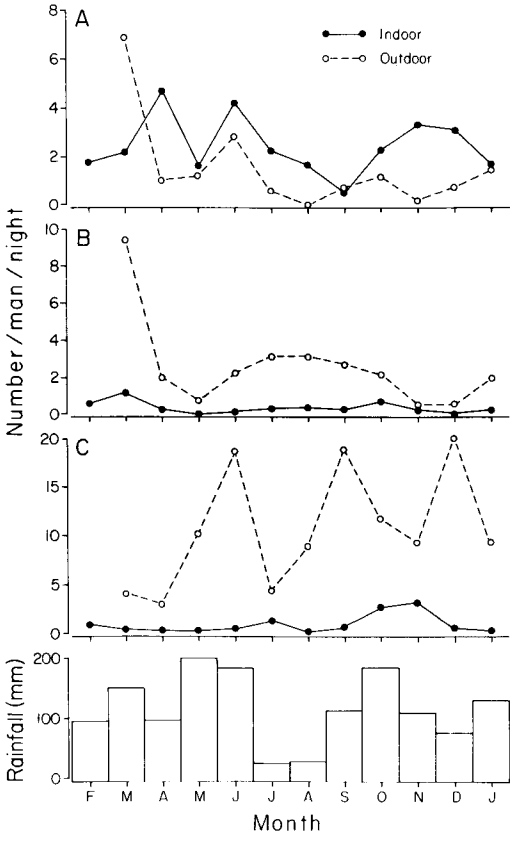

Fig. 1. Monthly average indoor and outdoor man-biting rates for (A) *Culex quinquefasciatus*, (B) *Mansonia africana* and (C) *Ma. uniformis*, in relation to total monthly rainfall, at the Kisian site, February 1987 to January 1988.

collected as adults in these 2 sites represent only the common nocturnally-active species biting man and domestic animals, and resting in and around houses. Undoubtedly, additional species could be detected by further adult sampling and larval surveys.

This study identified 16 man-biting culicine species at Kisian and 9 at Saradidi during 745 man-nights collection effort over one year. Only 5 species in Kisian, *Ae. mcintoshi*, *Cq. fuscopennata*, *Cx. quinquefasciatus*, *Ma. africana* and *Ma. uniformis*, and one species in Saradidi, *Cx. quinquefasciatus*, were collected commonly at night feeding on humans. Resident exposure inside houses, based on monthly average man-biting rates, was estimated to be ca. 1,277 bites/man/year at Kisian and 720 in Saradidi. There were significant monthly differences in biting rates which were associated with seasonal rainfall, especially at Saradidi where populations were more dependent upon temporary larval development sites during the rainy seasons.

Blood meal identification confirmed that humans and cows were the primary hosts for the common culicine species. A higher proportion of human blood meals were detected for mosquitoes collected inside houses compared with those collected outdoors. Chandler et al. (1975a), in a more extensive study on the Kano Plain, found similar feeding patterns.

This study provides baseline information on culicine mosquitoes in 2 sites targeted for future malaria vaccine trials. These sites were initially selected because there was no evidence for filariasis transmission, and the prevalence of arboviruses was suspected to be low (Johnson et al. 1977a, 1977b). In this study, biting rates for *Cx. quinquefasciatus*, a vector of filariasis, were about 15 times lower than in a filariasis endemic urban area on the Kenyan coast (Wijers and Kiilu 1977). During initial malaria vaccine trials involving nonindigenous volunteers, exposure to natural malaria transmission is expected to be less than one month. Based on average daily biting rates for common culicine species, volunteers exposed inside houses, outdoors or in tents would be expected to receive more than 5

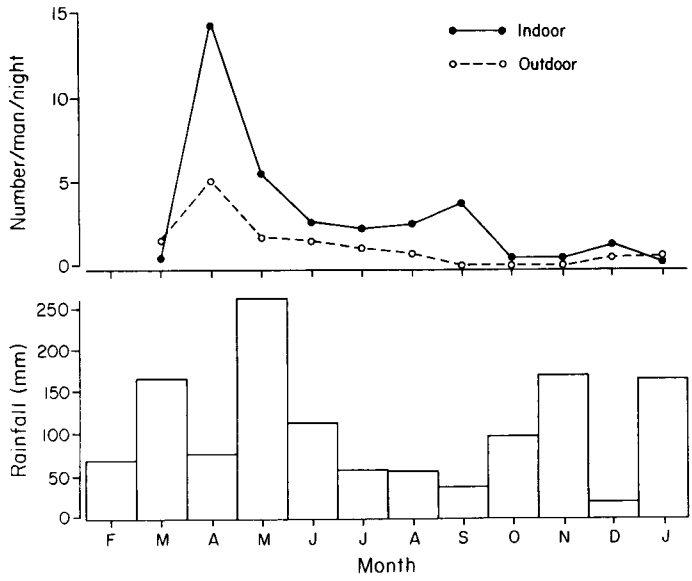

Fig. 2. Monthly average indoor and outdoor man-biting rates for *Culex quinquefasciatus*, in relation to total monthly rainfall, at the Saradidi site, March 1987 to January 1988.

Table 3. Host blood meal sources for 6 mosquito species collected inside houses (I) and from outdoor sites (O) from the Kisian and Saradidi sites, western Kenya.

Mosquito species	Habitat[1]	Total tested	% identified	% of identified blood meals							
				Human	Cow	Donkey	Goat/ sheep	Dog	Cat	Chicken	Mixed
Aedes mcintoshi	O	11	90.9		90.0						10.0
Coquillettidia fusco-pennata	I	1	100.0		100.0						
	O	20	45.0		55.6	11.1		11.1		11.1	11.1
Culex quinquefascia-tus	I	1,054	89.2	87.6	1.2	1.4	0.5	1.6	0.8	3.7	3.2
	O	87	86.2	22.7	61.3	2.7		4.0		8.0	1.3
Culex nebulosus	O	3	66.7							100.0	
Mansonia africana	I	7	100.0	57.1				14.3	14.3	14.3	
	O	8	87.5		100.0						
Mansonia uniformis	I	15	86.7	84.6				7.7			7.7
	O	20	95.0	5.3	84.2						10.5

[1] Collection techniques inside houses included aspiration collections and pyrethrum spray catches; collections outdoors included CDC light traps and aspiration collections in vegetation.

bites per 30-day period from only 5 culicine species in Kisian and only one species in Saradidi.

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