Parasitol Res (2012) 110:61–71
DOI 10.1007/s00436-011-2449-6

ORIGINAL PAPER

Mosquito species abundance and diversity in Malindi, Kenya and their potential implication in pathogen transmission

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Received: 29 April 2010 / Accepted: 10 May 2011 / Published online: 31 May 2011

Abstract Mosquitoes (Diptera: Culicidae) are important vectors of human disease-causing pathogens. Mosquitoes are found both in rural and urban areas. Deteriorating infrastructure, poor access to health, water and sanitation services, increasing population density, and widespread poverty contribute to conditions that modify the environment, which directly influences the risk of disease within the urban and peri-urban ecosystem. The objective of this study was to evaluate the mosquito vector abundance and diversity in urban, peri-urban, and rural strata in Malindi along the Kenya coast. The study was conducted in the coastal district of Malindi between January and December 2005. Three strata were selected which were described as urban, peri-urban, and rural. Sampling was done during the wet and dry seasons. Sampling in the wet season was done in the months of April and June to cover the long rainy season and in November and December to cover the short rainy season, while the dry season was between January and March and September and October. Adult mosquito collection was done using Pyrethrum Spray Collection (PSC) and Centers for Disease Control and Prevention (CDC) light traps inside houses and specimens were identified morphologically. In the three strata (urban, peri-urban, and rural), 78.5% of the total mosquito (n=7,775) were collected using PSC while 18.1% (n=1,795) were collected using the CDC light traps. Using oviposition traps, mosquito eggs were collected and reared in the insectary which yielded 329 adults of which 83.8% (n=276) were *Aedes aegypti* and 16.2% (n=53) were *Culex quinquefasciatus*. The mosquito distribution in the three sites varied significantly in each collection site. *Anopheles gambiae*, *Anopheles funestus* and *Anopheles coustani* were predominant in the rural stratum while *C. quinquefasciatus* was mostly found in urban and peri-urban strata. However, using PSC and CDC light trap collection techniques, *A. aegypti* was only found in urban strata. In the three strata, mosquitoes were mainly found in high numbers during the wet season. Further, *A. gambiae*, *C. quinquefasciatus*, and *A. aegypti* mosquitoes were found occurring together inside the houses. This in turn exposes the inhabitants to an array of mosquito-borne diseases including malaria, bancroftian filariasis, and arboviruses (dengue fever, Yellow fever, Rift Valley fever, Chikungunya fever, and West Nile Virus). In conclusion, our findings provide useful information for the design of integrated mosquito and disease control programs in East African environments.

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Introduction

The most important mosquito species along the Kenyan coast in terms of transmission of disease pathogens to humans include *Anopheles gambiae* Giles, *Anopheles arabiensis* Patton, *Anopheles merus* Donitz, *Anopheles funestus* Giles (Mbogo et al. 2003), *Culex quinquefasciatus* Say (Mwandawiro et al. 1997), *Mansonia africana* Theobald and *Aedes aegypti* L. (Midega et al. 2006). These mosquito species are responsible for the transmission of malaria (*A. gambiae*, *A. arabiensis*, *A. merus*, *A. funestus*), Bancroftian filariasis (*C. quinquefasciatus* and *A. gambiae*), dengue fever (*A. aegypti*), Rift valley Virus (*A. aegypti*), and Yellow fever (*A. aegypti*; Mwandawiro et al. 1997; Woods et al. 2002; Mbogo et al. 2003; Midega et al. 2006; Muturi et al. 2006). *C. quinquefasciatus*, initially considered an urban vector of filariasis, has also been shown to be an equally important vector in rural settings (Mwandawiro et al. 1997).

Rapid urbanization brings about major changes in ecology, social structure, and disease patterns in sub-Saharan Africa. It is estimated that 300 million people currently live in urban areas in Africa and two thirds of them are at risk of malaria and other mosquito-borne diseases (Keiser et al. 2004). There is a lack of understanding of the complex interactions between human social structure, the environment, and malaria infections (Donnelly et al. 2005; Hay et al. 2005; Omumbo et al. 2005).

Urbanization is defined as fundamental changes in occupation and land use at the community level (Nichter and Kendall 1991; Grimm et al. 2000). In many peri-urban areas, populations are still actively engaged in rural-type activity. Deteriorating infrastructure, poor access to health, water, and sanitation services, increasing population density and widespread poverty contribute to conditions that modify environment, which directly influences the risk of disease (Macintyre et al. 2002). Poor physical planning resulting into haphazard building and poor water management, as well as small-scale agriculture typical of peri-urban areas, provide extensive larval habitat for *A. gambiae s.s* and *A. arabiensis* (Khaemba et al. 1994; Robert et al. 1998; Keating et al. 2003) and occasionally *A. funestus* (Lindsay et al. 2004). Midega et al. (2006) found that container-breeding mosquito *A. aegypti* pupal productivity was higher in large containers than small ones and further outdoor water pails, metallic and plastic drums and tires were the most epidemiologically important container types with consistent pupal productivity.

This study evaluates mosquito vector abundance and diversity in urban, peri-urban, and rural sites in Malindi along the Kenya coast. One of the objectives was to provide information to help health policy advisory teams of the Ministry of Health and the Malindi Municipal Council in instituting the appropriate control measures for populations at risk of mosquito-borne diseases.

Materials and methods

Study area

The study was conducted in the coastal district of Malindi, which is the tenth largest urban center in Kenya. Malindi is located 108 km north of Mombasa city. According to the 2009 Kenya Population and Housing Census, the district had a population of 400,154 with a population of ≈140,000 people living within the Municipality (Kenya National Bureau of Statistics 2009). Malindi is a major tourist destination and it receives thousands of tourists from different parts of world every year. Mean daily minimum and maximum temperatures are 22°C and 30°C, respectively, with a mean relative humidity of 65%. Coastal Kenya experiences two major rainy seasons: the long rains from April to August and the short rains from October to December.

Study sites

Three strata were selected which were described as urban, peri-urban, and rural based on previous sampling strategy (Keating et al. 2003; Midega et al. 2006). These strata varied in their levels of development and the system of physical planning. Briefly, the urban stratum was characterized by paved roads, piped water, planned housing, drainage services, and electricity lines. This area houses mostly government and municipal council offices and there are hotels in this area. However, due to some socio-economic stress some slum-like settlement has been constructed in upper northwestern side of the urban stratum. The peri-urban stratum lies between the urban and rural strata with some pockets of farming and only a patchy distribution of piped water and electricity. The housing in this area does not follow an organized physical planning system. The roads are not paved and have depressions during the rainy season that fill with water making them almost impassable by vehicles. The rural stratum was characterized by extensive farming, a lack of electricity, and a lack or scarcity of piped water. The houses in this area do not conform to any planned system but they are organized depending on the land ownership pattern. The rural stratum is mainly agricultural and the inhabitants are subsistence farmers and keep livestock mainly cattle, goats, and chicken. The houses in this stratum are scattered with the inhabitants mostly living in clusters.

A systematic sample with a random start was used to select individual grid cells (area) within the urban, peri-urban, and rural sites. The sampling interval was calculated, for each site using the formula $I=F/S$, where I is the sampling interval for each stratum, F the total number of grid cells (area) in each stratum, and S the desired sample size for each stratum. In cases where the interval was not a whole number, the outcome was rounded to the nearest integer. Any grid cells that did not contain households were dropped and an adjacent one was randomly picked. The heads of the selected households were asked for, and gave, their informed consent. The same houses were visited by the field team once in each of the cross-sectional surveys. If access to a selected household was denied or impossible (because the house was empty and locked), then the nearest house to it was visited instead.

Figure 1 shows the distribution of sampling points within the urban, peri-urban, and rural strata. The study area has previously been described (Keating et al. 2003; Midega et al. 2006). In the urban stratum, sampling was done in five villages namely: Barani, Central, Kisumu Ndogo, Maweni, and Shella. In the peri-urban, sampling was done in four villages namely Furuzi, Kibokoni, Muyeye, and Mtangani. In the rural stratum, the villages selected: Burangi, Ganda, Kijiwe Tanga, Mkao Moto, Mugurureni, and Sabaki. From each selected village, ≈10 houses were then randomly picked for adult mosquito sampling.

Seasonality

Sampling was done four times between January and December 2005. Sampling was done twice during the wet and twice during the dry seasons. The year was divided into four seasons namely long wet season between April and August, short wet season between November and December, long dry season between January and March and Short dry season between August and September. Sampling in the wet season was done during the months of April and June to cover the long wet season, and during the months of November and December to cover the short wet season. During the dry season, sampling was done between January and March to cover the long dry season and in September for the short dry season. In each sampling cycle, the entomological sampling started at the urban strata, followed by peri-urban then rural stratum. It was organized that there were no breaks in between the sampling in the strata.

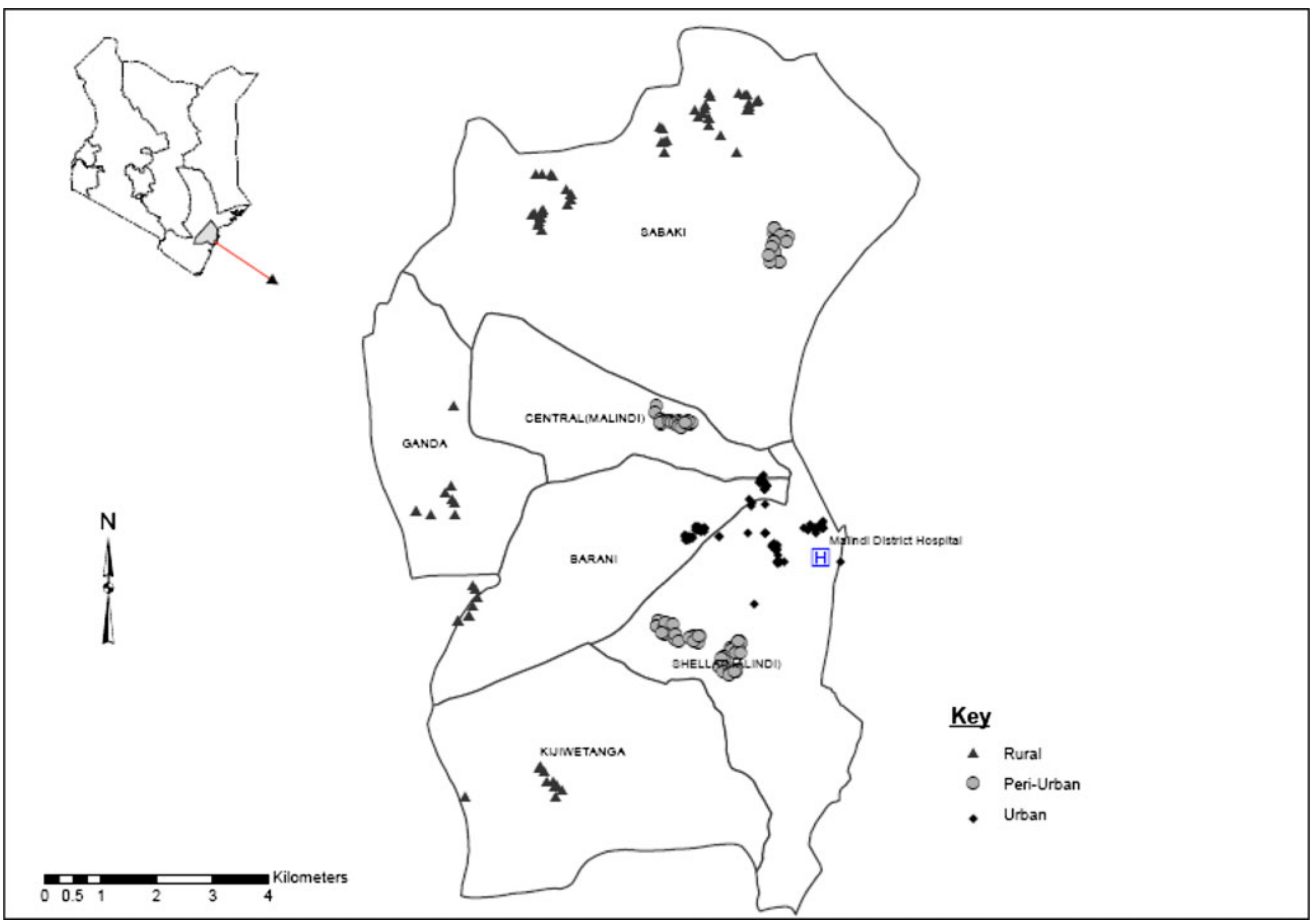

Fig. 1 Map showing the distribution of the sampling points in urban, peri-urban, and rural strata

Adult mosquito sampling and identification

Adult mosquito collections were done using Pyrethrum Spray Collection (PSC) and CDC Light Traps (LT) inside houses (WHO 1975). PSC was done in the morning hours between 0700 and 1200 hours while CDC light traps were set in the evening at 1800 hours, with removal of mosquitoes the next morning at 0600 hours. From each stratum, approximately 60 houses were used for PSC while LT were set in 20 houses in each stratum. The mosquitoes along the Kenyan coast are still susceptible to pyrethroids as recently shown. Studies in between February and April 2010 along the Kenya coast revealed that over 95% of *A. gambiae* mosquitoes tested for pyrethroids (n=425), deltamethrin (n=325), fenitrothion (n=125), bendiocarb (n=125), and DDT (n=125) were susceptible (Mbogo et al., personal communication). Consequently, sampling using PSC which is a gold standard is still effective as a sampling tool.

To sample aedine mosquitoes, oviposition traps were used. Ten oviposition traps (CDC Ovitraps) were randomly set in different households in each stratum. These oviposition traps were set at the beginning of collection of mosquitoes by PSC and LT and then were removed on the fifth day. The eggs collected in the oviposition traps were transferred to larval rearing pans (30×24 cm) in the insectary. After the eggs hatched into larvae, they were kept at an initial density of 14 larvae/cm^2 of pan surface area and then reared under insectary conditions. The emergent mosquitoes were then morphologically identified. The sampling was designed in such a way that in any given season, sampling began in the urban strata, then peri-urban, and finally the rural strata.

The collected mosquitoes were sorted according to subfamily as anopheline culicines and *Aedes*. These mosquitoes were further identified on the basis of morphologic characters according to keys of Gillies and Coetzee (1987) and Edwards (1941) to species. The *A. gambiae* complex was further identified to sibling species by a polymerase chain reaction (PCR); (Paskewitz and Collins 1990; Scott et al. 1993). Primers were employed specific to the only three members of the *A. gambiae* complex present along the Kenya coast, namely *A. gambiae s.s.*, *A. arabiensis*, and *A. merus*.

Statistical analysis

Data from precoded forms were checked for accuracy, logic, and range using SPSS version 15.0 (SPSS, Inc., Chicago, IL, USA). Omissions and errors were corrected. Variation in adult mosquitoes between collection sites was compared by Student's t test while the differences in adult mosquito abundance between villages were compared using one-way analysis of variance test (ANOVA). Where significant differences were observed in an ANOVA test, the Tukey's honestly significant difference (HSD) test was used to separate the means. Statistical analyses were done using log transformed ($\log_{10} n+1$) adult mosquito counts to normalize the data. Results were considered significant at $p<0.05$.

The Shannon diversity index (H) was used to characterize species diversity in the three study sites in Malindi. Shannon's index accounts for both abundance and evenness of the species present. The proportion of species i relative to the total number of species (pi) is calculated and then multiplied by the natural logarithm of this proportion (lnpi). The resulting product was summed across species and multiplied by −1 (Magurran 1988; Rosenweig 1995).

$$H = -\sum_{i=1}^{S} Pi \; 1n \; Pi$$

Shannon's equitability (EH) can be calculated by dividing H by Hmax (where Hmax=ln$S$, the total number of species in the community (richness). Equitability assumes a value between 0 and 1, with 1 being complete evenness.

Results

Mosquito sampling

A total of 9,899 adult mosquitoes were collected by PSC and LT from the three strata (urban, peri-urban, and rural). Of these, 78.5% of the total mosquitoes (n=7,775) were collected using PSC, 18.1% (n=1,795) by LT, while only 3.3% (n=329) were collected using the ovitraps (Table 1). Significantly more mosquitoes were captured by PSC compared to LT (t=148.88, $p<0.001$). Further analysis using one-way ANOVA showed the three strata varied significantly in mosquito abundance ($F_{(1,2)}$= 49.981, $p<0.001$).

Oviposition traps

A total of 391 larvae emerged from the oviposition traps collections, of which 45.8% (n=179) were from urban stratum, 46.8% (n=183) from peri-urban, and 7.4% (n=29) from rural. The rearing of these larvae at the insectary yielded 329 adults of which 83.9% (n=276) were *A. aegypti* and 16.1% (n=53) were *C. quinquefasciatus*. Most of the *Aedes* mosquitoes were collected in urban and peri-urban strata (92.8%, n=256) while a few were collected in the rural site (7.2%, n=20).

Table 1 Mosquito species composition and distribution in urban, peri-urban, and rural strata

Species	Strata									Total
	Urban			Peri-urban			Rural			
	PSC	LT	Ovitrap	PSC	LT	Ovitrap	PSC	LT	Ovitrap	
A. gambiae	17	0	0	15	14	0	91	19	0	156
A. funestus	0	0	0	0	0	0	9	7	0	16
A. coustani	0	0	0	0	0	0	3	0	0	3
A. nilli	0	0	0	0	0	0	2	0	0	2
C. quinquefasciatus	2,925	819	23	3,321	545	26	1,331	275	4	9,269
C. thalassius	1	0	0	1	5	0	0	1	0	8
C. tritaeniorhynchus	0	0	0	1	3	0	0	0	0	4
C. sitiens	0	0	0	0	1	0	0	0	0	1
C. theileri	0	0	0	0	1	0	0	0	0	1
A. aegypti	21	2	127	2	0	129	0	0	20	301
A. tricholabis	2	0	0	0	0	0	0	0	0	2
A. dalzieli	1	0	0	1	0	0	0	0	0	2
A. sudanensis	1	0	0	0	0	0	0	0	0	1
M. Africana	10	0	0	15	80	0	2	13	0	120
M. uniformis	1	0	0	2	8	0	0	1	0	12
C. azurites	0	0	0	0	1	0	0	0	0	1
Total	2,979	821	150	3,358	658	155	1,438	316	24	9,899

PSC Pyrethrum Spray Collection, *LT* CDC Light Trap

Mosquito species composition

A total of 16 different species of mosquitoes were collected in the three sites which included four *Anopheles* species namely *A. gambiae s.l.*, *A. funestus*, *A. coustani*, and *A. nilli*; five *Culex* spp: *C. quinquefasciatus*, *C. thalassius*, *C. tritaeniorhynchus*, *Culex sitiens*, and *C. theileri*; two *Mansonia* spp: *M. africana* and *M. uniformis*; four *Aedes* species: *A. aegypti*, *Aedes sudanensis*, *Aedes tricholabis*, and *Aedes dalzieli*, and one *Coquilletidia*, *Coquilletidia aurites* (Table 1). *A. gambiae* s.l was more prevalent in the three sites compared to other *Anopheles* species, *A. funestus*, *A. coustani*, and *A. nilli*. Further analysis by rDNA PCR technique of the *A. gambiae* complex yielded 59.5% *A. arabiensis*, 22.4%, *A. merus*, and 18.1% *A. gambiae s.s.*

C. quinquefasciatus was the predominant species and commonly observed in all the three sites and it accounted for 99.8% all culicine collected. Other culicine species *C. thalassius*, *C. tritaeniorhynchus*, *C. sitiens*, and *C. theileri* occurred in low numbers but mostly in urban and peri-urban strata. *Mansonia* spp were found in both urban and peri-urban strata

Spatial distribution of mosquito species

The mosquito species varied in abundance in the three strata. For the anophelines, *A. gambiae* s.l. was more common in the rural strata and their abundance decreased towards the urban stratum while *A. funestus*, *A. coustani*, and *A. nilli* were only found in the rural strata (Table 1). One-way ANOVA showed that there was significant variation in *A. gambiae* s.l. distribution in the three strata ($F_{(2,\ 2,017)}$=14.111, p<0.001) and further, rural stratum was significantly different from urban and peri-urban strata (Tukey's HSD∝0.05). *C. quinquefasciatus* was predominantly found in urban and peri-urban strata and was less common in the rural stratum ($F_{(2,2017)}$=18.762, p<0.001). *A. aegypti* was predominant in urban stratum but none were collected in the rural stratum.

Figure 2 shows the proportion of mosquitoes collected in the three strata. The mosquito distribution in the three strata varied significantly ($F_{(1,2)}$=7.421, p<0.001). The distribution of *A. gambiae* s.l. in rural strata varied significantly ($F_{(10,642)}$=14.815, p<0.001). *C. quinquefasciatus* distribution varied significantly in the rural strata ($F_{(10,642)}$=14.179, p<0.001). In peri-urban strata, *C. quinquefasciatus* distribution varied in each collection villages ($F_{(3,654)}$=4.009, p= 0.008). In the urban stratum, distribution of *C. quinquefasciatus* significantly varied ($F_{(4,704)}$=7.92, p<0.001) in the collection villages.

Species diversity and evenness

The *H* was used to characterize species diversity in the three strata in Malindi, Kenya. The *H* and EH of mosquito species in the rural stratum (H=0.4420, EH=0.1522) were much higher than in the urban and peri-urban strata (H=0.2204, EH=0.0794, urban and H=0.3325, EH=0.1108, peri-urban). This implies that the rural stratum had a greater number of species present with the individuals in the community being distributed more equitably among these species (Table 2). Further analysis showed that the urban had a significantly higher species diversity compared to the peri-urban strata (χ^2=3.9054, df=1, p=0.048). However, rural stratum had a significantly higher diversity and evenness compared to the other strata.

Seasonal distribution of mosquitoes in the three strata

Figure 3 shows the distribution of mosquitoes in urban, peri-urban, and rural strata during the wet and dry season. More *A. gambiae* s.l. was found during the wet season in both rural and peri-urban strata whereas its occurrence was observed during the dry season in urban stratum. *A. funestus* was only found in the rural stratum during the dry season while *A. coustani* was found in rural stratum during the wet season. The population of *C. quinquefasciatus* was high during the wet season in the three strata (urban, peri-urban, and rural). *A. aegypti* was mostly found in the urban stratum and the distribution was almost the same during the wet and dry season.

Discussion

Along the Kenya coast, the major mosquito-borne diseases are malaria and filariasis which are mainly associated with *A. gambiae s.s.*, *A. arabiensis*, *A. merus*, and *A. funestus* for malaria and *C. quinquefasciatus* for filariasis. Most entomological studies along the Kenya coast have concentrated on malaria (Mbogo et al. 1993a, b, 1995, 2003; Kabiru et al. 1997; Gu et al. 2003; Mwangangi et al. 2004; Keating et al. 2005) and bancroftian filariasis (Wijers and McMahon

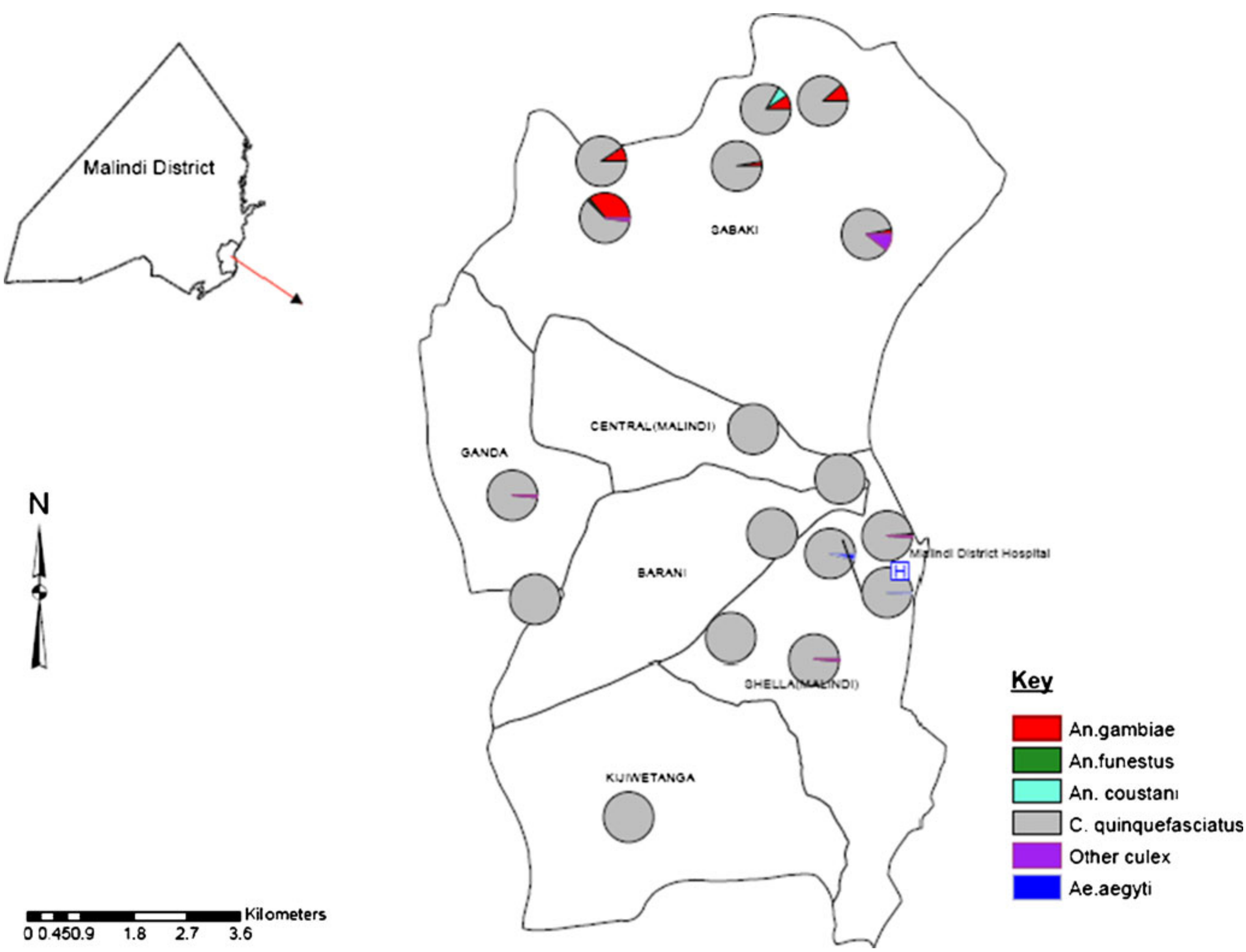

Fig. 2 The spatial distribution of mosquito species in the three sites

Table 2 Species diversity and evenness in three sites in Malindi Kenya

Distribution	Site	All mosquito species (*n*)[a]
Shannon's Diversity Index (*H*)	Urban	0.2204 (9)
	Peri-urban	0.3325 (11)
	Rural	0.4420 (9)
Shannon's Equitability (EH)	Urban	0.0794 (9)
	Peri-urban	0.1108 (11)
	Rural	0.1522 (9)

[a] The values in parentheses represent the number of species collected in the survey

1976; Wijers 1977a, b; Wijers and Kiilu 1977; Wijers and Kinyanjui 1977; Wijers and Kaleli 1984; Mwandawiro et al. 1997; Muturi et al. 2006). Very little information exists on the potential mosquito vectors of arboviruses along the Kenya coast. The arboviruses which have been reported along the coastal strip of Kenya include Dengue fever, Rift Valley fever, Chikungunya, and Yellow fever (Midega et al. 2006). There have been very few studies on these neglected diseases in Kenya and East African Region and recently there have been upsurges in the arboviral disease transmission (CDC 2007). Majority of these studies have been carried out in rural areas with very few studies being carried out in urban sites (Macintyre et al. 2002; Keating et al. 2003; Midega et al. 2006). In our study, we sought to understand mosquito species diversity and distribution in rural, peri-urban, and urban sites, which would show for the first time the presence of different vectors in these diverse environments.

The presence of *Anopheles*, *Culex*, *Mansonia*, and *Aedes* mosquitoes in this area exposes the people in the three sites to mosquito-borne diseases including malaria, bancroftian filariasis, and arboviruses. *A. gambiae* and *A. funestus* are major vectors of malaria in Kenya (Beier et al. 1987, 1994; Githeko et al. 1993; Shililu et al. 1998; Mbogo et al. 2003) while *A. gambiae*, *A. funestus*, and *C. quinquefasciatus* are important in transmission of bancroftian filariasis (Wijers and Kiilu 1977; Mwandawiro et al. 1997; Muturi et al. 2006). In Kenya and the East African region, several arboviruses have been documented with *Culex* and *Aedes* mosquitoes been incriminated in their transmission (Saleh et al. 1985; Hyams et al. 1986; Reiter et al. 1998; Sanders et al. 1998; Woods et al. 2002).

A. coustani and *M. africana* are important in transmission of Rift Valley fever virus (Logan et al. 1991; Gordon et al. 1992; Fontenille et al. 1998; Reiter et al. 1998; Diallo et al. 2005). The latest incidence of this disease was reported in North Eastern Province of Kenya in November 2006, spreading gradually in early 2007 into the Coast, Central and Rift Valley Provinces (CDC 2007). The outbreak claimed about 200 lives in the affected areas and it was estimated that the country required about U$ 29 million to effectively contain the virus (CDC 2007). At the same time (starting in mid-January 2007), an outbreak flared in Tanzania and quickly spread to 10 administrative districts causing 109 deaths out of the 294 human cases reported (AfrolNews 2007; WHO 2007). Recently, Rift Valley fever outbreak was reported in Mauritania in the West Africa (Faye et al. 2007). Besides Rift Valley fever virus, during 2005–2006, large-scale Chikungunya fever epidemics affected western Indian Ocean Islands and India in the islands of Mayotte, Mauritius, and the Seychelles (WHO 2006; Chretien et al. 2007). In Kenya, there have been outbreaks of chikungunya along the Kenya coast in the 2004 in Lamu and then in Mombasa (Breiman Personal Communication, Sang R, Personal Communication) in which *A. aegypti* was the main vector.

Beside the potential in pathogen transmission, some of the mosquito genera are mostly involved in biting nuisance. The biting nuisance is mostly found in the urban and peri-urban strata where the species richness was highest. The peri-urban stratum is mostly a transitional zone which includes some rural-like agricultural activities and urban-like economic activities. Many man-made habitats have been created which are colonized by various species of mosquitoes within the urban and peri-urban strata. The biting nuisance in an area causes discomfort amongst the inhabitants of an area and allergic reactions for the people who react to bites from insects. With the presence of vectors for malaria, bancroftian filariasis, and arboviruses, mosquito control initiatives should be instituted to target mosquitoes of diverse feeding and resting behaviors.

A significant variation in mosquito density and species richness was observed in the three sites. These variations may be due to the observed differences in the diversity of aquatic habitats among the three sites. The peri-urban area had more diverse habitat types, thereby supporting diverse mosquito species. Previous studies have reported a positive relationship between habitat type diversity and mosquito species richness (Beier et al. 1990; Shililu et al. 2003). The distribution and abundance of mosquito larvae reflect the oviposition preferences of adult females and ability of the immature stages to tolerate the conditions that prevail in the aquatic habitats (Reisen et al. 1981). The distribution of the adult mosquitoes showed that *A. gambiae* s.l. mosquitoes were able to utilize more breeding habitats at the rural site, but appear to be also able to adapt to the environmental challenges caused by urbanization. Different investigators have found malaria vectors breeding in urban habitats (Robert et al. 1998; Keating et al. 2004) and further malaria transmission in urban areas (Keiser et al. 2004). In Malindi, recent data show that there is 3.66% (n=771; *A. gambiae* s.

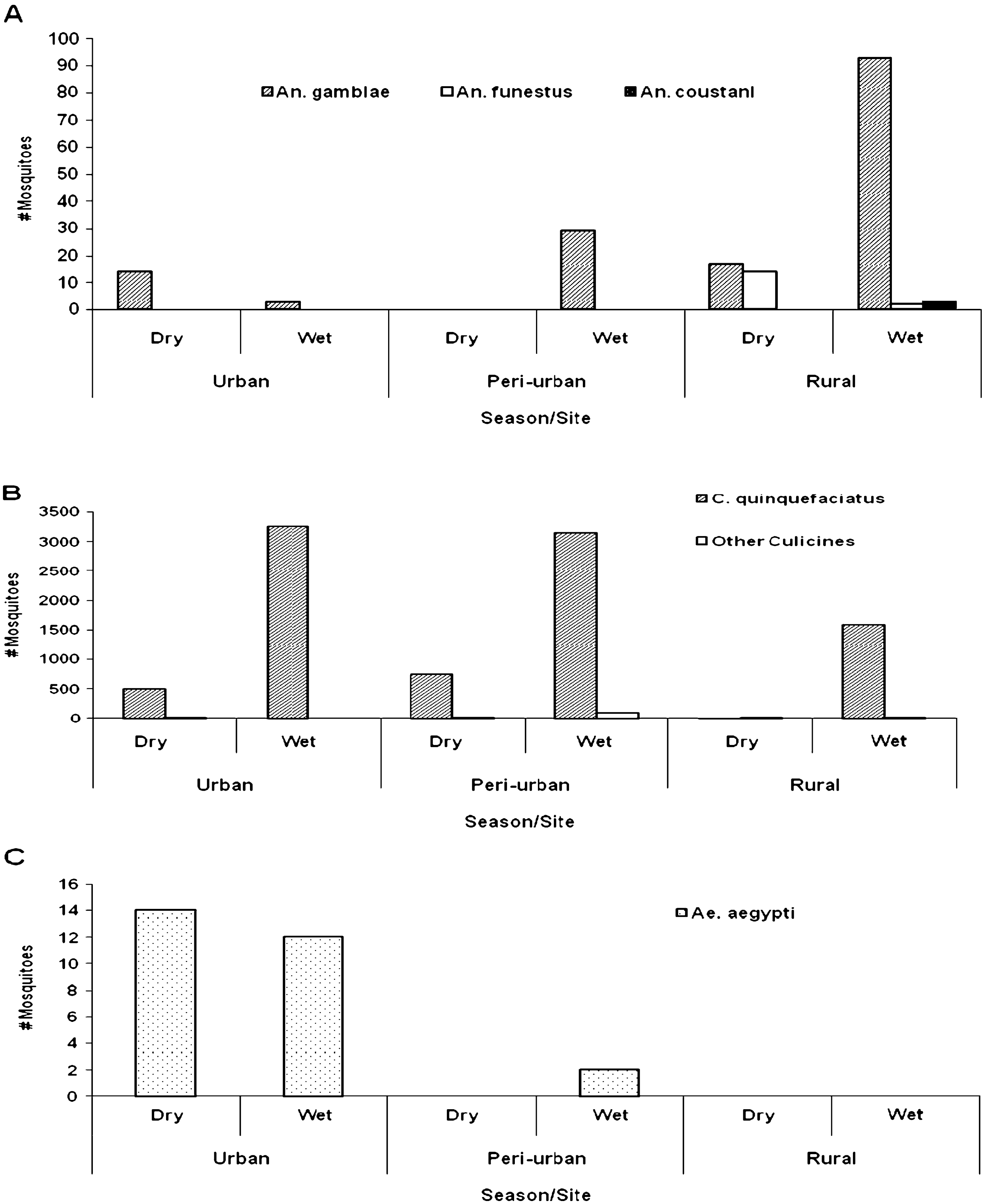

Fig 3 Seasonal variation of **a** *Anopheles*, **b** *Culex*, and **c** *Aedes* mosquitoes in the three sites during both the dry and wet season

l.) sporozoite infection from the rural strata while peri-urban and urban strata accounts for <0.5% ($n=145$; *A. gambiae* s.l.) sporozoite infectivity (Mbogo, personal communication). Malaria transmission in both in rural and urban sites currently poses a challenge to health advisory teams on control measures for this disease.

Our results show that *C. quinquefasciatus* was found in the three sites (urban, peri-urban, and rural). *C. quinquefasciatus* mosquitoes have long been known to use dirty and polluted urban habitats (Hassan et al. 1993). Recent studies have shown that *A. gambiae s.s.* and *C. quinquefasciatus* co-exist in the same habitats (Minakawa et al. 1999; Keating et al. 2004; Mwangangi et al. 2007). *A. aegypti* was mainly collected in the urban sites with very few collected in the peri-urban sites. This implies that *A. aegypti* which oviposits mostly in containers is urban mosquito (Midega et al. 2006). This may be associated with the availability of oviposition sites (containers) in urban areas. Although through the use of oviposition traps, we also found also *A. aegypti* in rural sites; however, the numbers were low. This confirms the recent survey on domestic containers in rural, peri-urban, and urban sites in Malindi, which found *A. aegypti* pupae occurring in the three sites (Midega et al. 2006).

Our findings provide significant information useful in designation of an integrated mosquito and disease control strategy in response to the recent emergence and reemergence of mosquito-borne diseases in the tropics. Currently, there is a major scale-up of use of long-lasting insecticide-treated bed nets (LLINs) in Kenya as the main anti-mosquito control measure (Noor et al. 2007, 2008). To greatly impact on the mosquito-borne diseases, there is a need to embrace an integrated vector management (IVM) strategy which targets both the adult mosquitoes and the immature stages. IVM is defined as a rational decision-making process for the optimal use of resources for vector control (WHO 2004). An integrated vector control program is advantageous because in addition to reducing the risk of mosquito-borne diseases, it could also result in an overall reduction in densities of nuisance mosquitoes making it more acceptable to the resident community. This strategy main advantage is that it target mosquitoes in all stages in their life cycle (adults and the immature stages) and its operation at the community level. At adult stages, it would be important to advocate for proper use of LLINs and this coupled with health-promotion education at the community level in which communities are given skills on mosquito control will result in minimizing the human–vector contact. At the immature stages, communities are trained on environmental management (draining and filling) and possibly the use of larvicides such as *Bacillus thuringiensis var Israelensis* (Mwangangi et al. 2010) which targets mostly habitats used by *Anopheles* and Culicines. Additionally, proper disposal of containers within the homesteads and closing the water storage containers inside the houses will tackle the aedian populations. The integrated vector management approach (WHO 2004) should be implemented at community level involving the health advisory teams, nongovernmental organizations, communities, and the hoteliers in Malindi. This all-inclusive approach would lower the mosquito populations consequently reducing the risk of mosquito-borne infections.

Acknowledgement We are grateful to Rosemary Wamae, Gabriel Nzai, Festus Yaa, and Shida David for help in field collections. We acknowledge the communities in the villages for giving their consent for our field team to work in their villages and houses. This work was supported by EHP grant and NIH Exploratory Centers grant (P20 RR020770). Dr. Beier was also partially supported by the Abess Center for Ecosystem Science and Policy, University of Miami. Additional support was by the Biovision Foundation of Switzerland through International Centre of Insect Physiology and Ecology (ICIPE). This paper has been published with the permission of the Director of the Kenya Medical Research Institute (KEMRI) and the Director General of ICIPE.

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