Tropical Biomedicine 37(3): 637–649 (2020)

Dynamics of malaria vector indices in two vegetation zones within North Eastern Adamawa State, Nigeria

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Received 10 March 2020; received in revised form 12 June 2020; accepted 15 June 2020

Abstract. Studies profiling community and zonal malaria entomological risk indices are required to identify high risk areas where targeted control resources are most needed or likely to have the greatest impact on reducing risk of malaria infection. This study presents a first report on malaria vector risk indices in two vegetation zones within Adamawa state, Nigeria. Endophilic mosquitoes were collected for one year in selected communities in the Guinea and Sudan savanna zones within the State. *Plasmodium falciparum* Sporozoite and human blood meal ELISA assays were carried out on the female *Anopheles* mosquitoes collected. Sibling species composition of the *An. gambiae* complex were determined using PCR assays. Mean numbers of mosquitoes in the Guinea savanna communities were significantly ($t = 7.73$, $DF = 11$, $p < 0.001$) higher than the Sudan. Man-biting rates ($F = 2.76$, $p = 0.13$) of *Anopheles* mosquitoes were higher in the Guinea but not significantly different from Sudan savanna. Sporozoite rates of mosquitoes within the Guinea savanna were 2.7 times higher than the Sudan. The predominant *Anopheles coluzzii* species encountered in the state had higher overall human blood indices (0.63) and sporozoite rates (6.9%) compared to *An. gambiae* (0.39, 1.9%) and *An. arabiensis* (0.58, 2.3%) respectively. Overall annual human blood indices (0.59) of mosquitoes in Adamawa were lower compared to reports from other States. Prevalence and higher transmission risks indices of endophilic *An. coluzzii* mosquitoes reveal the need for LLIN and management of relatively permanent *An. coluzzii* breeding sites in the State. Widespread cattle rearing lifestyle and lower human blood indices of mosquitoes in the study area suggest the need to investigate cattle blood indices of the mosquitoes in the state. Higher entomological risk indices in the Guinea Savanna zone provide baseline information for prioritization of malaria vector control supplies within the State.

INTRODUCTION

Evidences of reductions in malaria disease burdens have been reported especially within the last decade. Between 2010 and 2018, malaria case incidence levels reduced by 70 and 22% in the WHO South-East Asia and the African Regions respectively (WHO, 2019). The global decline in malaria disease burdens have been linked partly with the deployments of malaria vector control tools such as long-lasting insecticidal nets (LLINs) and indoor residual spray (IRS). In Nigeria, where the highest (25%) global malaria burden occurs (WHO, 2019), LLIN distribution campaigns and pockets of IRS implementations have been ongoing since 2009. Consequently, the Nigerian population at risk sleeping under an insecticide-treated net (ITN) or protected by IRS have increased by at least 20% with a corresponding 20–40% decrease in malaria mortality rate between 2010 and 2015 (WHO, 2016). While the global search for new vector control tools continues, current gains can be sustained through informed localized interventions guided by

the knowledge of malaria entomological indices (WHO, 2013). Since intervention effects vary in space as driven by local endemicity levels, studies profiling community and regional malaria entomological risk indices are required to identify high risk areas where targeted strategies and resources are most needed or likely to have the greatest impact on reducing risk of malaria infection (Giardini *et al*., 2014). These kinds of studies are crucial to the sustenance and furtherance of the recorded malaria reduction rates which is already slowing down and has remained at similar levels between 2014 and 2018 (WHO, 2019). Intra-regional and country variations in malaria entomological indices have been reported across sub-Saharan Africa (Daygena *et al*., 2017; Ototo *et al*., 2015; Walker *et al*., 2013; Oduola *et al*., 2012; Kigadye *et al*., 2011; Tchuinkam *et al*., 2010). However, in Nigeria, much of the malaria vector risk indices data have been generated from the South Western part of the Country (Awolola *et al*., 2002; Oyewole *et al*., 2007; Oyewole *et al*., 2010; Oduola *et al*., 2013) leaving out other regions such as the North East where only few longitudinal studies involving proper characterization of malaria vector samples, using standard methods, have been reported (Yoriyo *et al*., 2014; Samdi, 2012). Adamawa is a unique North Eastern State representing one of the largest States in Nigeria. Some of its peculiarities include the presence of both Guinea and Sudan Savanna areas and the prevalence of flood plains with many rivers passing through the Fadama lands all over the State especially during the rainy season (Adewumi, 2013). Despite the foregoing and the data confirming Adamawa as the State with the highest malaria prevalence rate (55.5%) in the North Eastern region of Nigeria (NMEP, 2016), there has been no report, to our knowledge, on malaria vector risk indices in the different vegetation zones within the State. Such reports are necessary for successful planning, implementation and assessments of effective malaria vector control programmes within the State in order to contribute to the reduction of the malaria burden in the country. This study presents a first report on malaria vector indices across selected communities within the two vegetation zones in Adamawa state, Northeastern Nigeria.

MATERIALS AND METHODS

Study area and design

Adamawa State is one of the largest states in Nigeria, with about 38,700km^2 land area and an estimated human population of 4,502,132 (NIPC, 2020). It is located in North Eastern Nigeria with major vegetation formations comprising Guinea and Sudan Savannas (NIPC, 2020). Annual rainfalls in the Sudan (700mm-900mm, 3-4 months), Southern (1100mm-1600mm, 6-7 months) and Northern (900-1100mm, 4-5 months) Guinea Savanna zones of the state last for about three to seven months respectively (Akosim *et al*., 1999). The wettest months are August and September while the dry season starts in November and ends in April (Adebayo, 1999). Relative humidity is usually very low (20–30%) between January and March with increase as from April to a maximum of 80% in August and September (Adebayo, 1999). Adamawa is one of the Nigerian States with very high concentration of livestock, the most significant being the 3.5 million Adamawa gudali cattle managed in relatively small herd sizes by settled pastoralists who rarely move very far but send their cattle to favourable locales at the peak of the dry season (Tukur and Ardo, 1999). Four communities were selected on the basis of proximity to similar river tributaries which may form suitable breeding habitats for *Anopheles* mosquitoes (Table 1). Two of the communities (Bazza and Vimtim) are located in the Sudan Savanna while the other two (Imburu and Bachure) belong to the Northern Guinea Savanna zone, hereafter referred to as Guinea Savanna zone. The communities had houses without major barriers (ceilings and window nets) to mosquito entry and were similar in that some of the residents were settled pastoralists engaging in extensive cattle management systems. The community residents all lacked LLINs probably because of the long interval between the last LLIN

Table 1. Description of study communities in the two vegetation zones in Adamawa State

Vegetation Zone	Community	River tributaries present	Coordinates
Sudan Savanna	Bazza	Yedsaram	10°33.50N, 13°23.00E
Sudan Savanna	Vimtim	Yedsaram	10°23.50N, 13°21.00E
Guinea Savanna	Bachure	Benue	09°16.50N, 12°24.50E
Guinea Savanna	Imburu	Benue	09°30.00N, 11.5°20.00E

distribution campaign in the State in 2010 and the period of the study in 2016.

Endophilic mosquito collection and identification

Indoor resting mosquitoes were collected monthly between January and December, 2016 from ten rooms in each of the four communities using pyrethrum spray collection method. The room chosen in each house were used throughout the study. Each room was selected only if the occupants affirmed readiness to allow the use of the rooms throughout the period of the study. The number of persons that slept in each room over the night before mosquito collection was recorded for man-biting rates estimations (Shililu *et al*., 1998; WHO 2003). Each female mosquito sample collected was preserved on silica gel in 1.5ml Eppendorf tube for further analysis at The Nigerian Institute of Medical Research, Lagos. All samples were identified morphologically (Gillies and Coetzee, 1987) before species-specific PCR (Scott *et al*., 1993) and PCR-RFLP (Favia *et al*., 1997) assays were conducted on 98% (161/164) and 95% (437/458) of the female *An. gambiae* s.l collected in Sudan and Guinea Savanna zones respectively.

Determination of *P. falciparum* infection and presence of human blood in mosquitoes

Plasmodium falciparum sporozoite ELISA (Wirtz *et al*., 1987) were conducted on heads-thoraces of all collected female *An. gambiae* (s.l.) samples using monoclonal antibodies and positive controls from Centers for Disease Control and Prevention (Atlanta, USA). Human blood meal ELISA (Beier *et al*., 1988) carried out on all blood-fed and half-gravid samples were done using human serum and monoclonal antibodies obtained respectively from Rockland immunochemicals (Gilbertsville, USA) and Kikergaard and Perry Laboratories (Gaithersburg, USA).

Data analyses

Recorded number of persons in the rooms was taken as a reflection of human availability for mosquito bites since the community residents were not sleeping under bed-nets. Proportion of blood-fed and half-gravid samples found with human blood was taken as Human blood index (HBI). Man-biting rates (MBR) were estimated as the number of blood-fed and half-gravid samples collected divided by the number of persons who slept in the rooms over the night before mosquito collection multiplied by HBI (Shililu *et al*., 1998; WHO 2003). Data obtained were transformed [$\sqrt{n}$ +0.5] (Ogbeigbu, 2005) to normal distribution. Mean numbers, human blood indices and man-biting rates of female *Anopheles gambiae* (s.l.) mosquitoes collected monthly in the two communities per zone were pooled and compared between the two zones. The Proportional data (HBI and MBR) were compared by logistic regression while mean numbers of mosquitoes were compared using Student's t-test (SPSS 16 software) at $p < 0.05$.

RESULTS

Numbers of female *Anopheles* mosquitoes collected monthly from the Guinea and Sudan savanna communities are presented in Table 2. Highest numbers of female

Table 2. Numbers of female *Anopheles* mosquitoes in the communities in Adamawa State

Month	Sudan Savanna Zone							Guinea Savanna Zone						
	Actual values			Total transformed value	Transformed values			Actual values			Total transformed value	Transformed values		
	Bazza	Vimtim	Total		Bazza	Vimtim	Total	Imburu	Bachure	Total		Imburu	Bachure	Total
Jan	3	6	9	3.08	1.87	2.55	4.42	27	3	30	5.52	5.24	1.87	7.11
Feb	3	6	9	3.08	1.87	2.55	4.42	15	5	20	4.53	3.94	2.35	6.29
Mar	10	4	14	3.81	3.24	2.12	5.36	31	9	40	6.36	5.61	3.08	8.69
April	3	5	8	2.92	1.87	2.35	4.22	43	12	55	7.45	6.59	3.54	10.13
May	3	3	6	2.55	1.87	1.87	3.74	18	0	18	4.30	4.30	0.71	5.01
June	10	3	13	3.67	3.24	1.87	5.11	35	17	52	7.25	5.96	4.18	10.14
July	18	5	23	4.85	4.30	2.35	6.65	37	24	61	7.84	6.12	4.95	11.07
Aug	29	11	40	6.36	5.43	3.39	8.82	32	23	55	7.45	5.70	4.85	10.55
Sept	6	3	9	3.08	2.55	1.87	4.42	15	28	43	6.59	3.94	5.34	9.28
Oct	4	9	13	3.67	2.12	3.08	5.20	25	16	41	6.44	5.05	4.06	9.11
Nov	5	5	10	3.24	2.35	2.35	4.70	22	5	27	5.24	4.74	2.35	7.09
Dec	6	4	10	3.24	2.55	2.12	4.67	14	2	16	4.06	3.81	1.58	5.39
Mean± S.D			**13.67± 9.36**	**3.63± 1.04** [a]	**2.77± 1.12**	**2.37± 0.48**	**5.14± 1.37**			**38.17± 15.76**	**6.09± 1.33** [b]	**5.08± 0.94**	**3.24± 1.48**	**8.32± 2.08** [b]

Transformation formula: N = √n+0.5, N-transformed value, n-actual value. Mean numbers with different letter superscript are significantly different at $p < 0.05$.

Anopheles mosquitoes were collected in both zones between the month of June and August. A total of 458 (Mean 38.17±15.76) female *Anopheles* mosquitoes was collected in the Guinea savanna compared to 164 (Mean 13.67±9.36) mosquitoes found in the Sudan savanna zone (Table 2). Mean numbers of female *Anopheles* mosquitoes collected in the two Sudan savanna communities were not significantly ($t = 1.329$, $DF = 11$, $p = 0.211$) different from each other. However, significant differences ($t = 4.680$, $DF = 11$, $p = 0.001$) were found between the numbers of female *Anopheles* collected in the two communities within the Guinea savanna zone of the state (Table 2).

Transformed mean of the total numbers of female *Anopheles* in the Guinea savanna zone (6.09±1.33) was significantly ($t = 7.731$, $DF = 11$, $p < 0.001$) higher than that of mosquitoes in the Sudan savanna (3.63±1.04) zone (Table 2). Between the two communities in each zone, the mean man-biting rates of *Anopheles* mosquitoes were not significantly different (Guinea $F = 0.045$, $p = 0.837$; Sudan $F = 1.685$, $p = 0.223$).

Mean man-biting rate of mosquitoes in the Guinea savanna (1.27±0.57) was higher compared to 0.51±0.38 in the Sudan savanna zone (Table 3).

Transformed mean man-biting rates of *Anopheles* mosquitoes were higher in the Guinea savanna (1.31±0.22) but not significantly ($F = 2.76$, $p = 0.13$) different from the Sudan savanna (0.99±0.17) zone (Table 3).

Human blood indices and man-biting rates of each *Anopheles* mosquito species encountered in all the communities are presented in Tables 4 and 5 respectively. Number of blood-fed *An. coluzzii* mosquitoes in the Guinea savanna (306) was 2.2 times higher than the number of the same species in the Sudan savanna (142) zone (Table 4). However, the number of *An. gambiae* mosquitoes in the Guinea savanna (89) zone was 5.2 times higher compared to the number of *An. gambiae* in Sudan savanna (17) zone (Table 3). Similarly, the number of *An. arabiensis* in the Guinea savanna was far higher (42 times) higher than the number of *An. arabiensis* in the Sudan savanna zone (Table 4).

Anopheles coluzzii had higher human blood indices and man-biting rates (0.63, 0.36) compared to *An. gambiae* (0.39, 0.05) and *An. arabiensis* (0.58, 0.03) species (Tables 4 and 5). In total, only about half (HBI 0.59) of all *Anopheles* mosquitoes

Table 3. Man-biting rates of *Anopheles* mosquitoes in the two zones in Adamawa State

Month	Sudan Savanna Zone				Guinea Savanna Zone			
	Actual values		Total	Transformed total value	Actual values		Total	Transformed total value
	Bazza	Vimtim			Imburu	Bachure		
January	0.13	0.33	0.46	0.98	0.78	0.10	0.88	1.17
February	0.07	0.23	0.30	0.89	0.47	0.14	0.61	1.05
March	0.33	0.19	0.52	1.01	1.41	0.21	1.62	1.46
April	0.00	0.24	0.24	0.86	1.34	0.27	1.61	1.45
May	0.25	0.06	0.31	0.90	0.39	0.00	0.39	0.94
June	0.31	0.12	0.43	0.96	1.45	0.67	2.12	1.62
July	0.72	0.19	0.91	1.19	1.32	0.78	2.10	1.61
August	1.00	0.54	1.54	1.43	0.89	0.65	1.54	1.43
September	0.29	0.00	0.29	0.89	0.37	0.94	1.31	1.35
October	0.21	0.47	0.68	1.09	0.87	0.56	1.43	1.39
November	0.13	0.12	0.25	0.87	0.83	0.21	1.04	1.24
December	0.11	0.13	0.24	0.86	0.47	0.13	0.60	1.05
Mean±S.D			0.51±0.38	0.99±0.17[a]			1.27±0.57	1.31±0.22[a]

Transformation formula: $N = \sqrt{n+0.5}$, N-transformed value, n-actual value. Mean numbers with the same letter superscript are not significantly different at $p < 0.05$.

Table 4. Human blood indices of different *Anopheles* mosquito species in the communities in Adamawa state

Zone	*An. gambiae*			*An. coluzzii*			*An. arabiensis*			Total No of *An.* with human blood	Total No of *An* with blood	HBI
	No of *An* with human blood	No of *An* with blood	HBI	No of *An* with human blood	No of *An* with blood	HBI	No of *An* with human blood	No of *An* with blood	HBI			
Sudan Savanna												
Bazza	0	6	0.00	48	90	0.53	0	1	0.00	48	97	0.4
Vimtim	2	11	0.18	39	52	0.75	0	0	0.00	41	63	0.65
Total	2	17	0.11	87	142	0.61	0	1	0.00	89	160	0.55
Guinea Savanna												
Imburu	24	62	0.39	132	197	0.67	22	35	0.63	178	294	0.61
Bachure	16	27	0.59	65	109	0.59	3	7	0.43	84	143	0.59
Total	40	89	0.45	197	306	0.64	25	42	0.59	262	437	0.59
Grand Total	**42**	**106**	**0.39**	**284**	**448**	**0.63**	**25**	**43**	**0.58**	**351**	**597**	**0.59**

HBI (Human blood index) = number of *Anopheles* with human blood/ number of *Anopheles* with blood.

Table 5. Man-biting rates of the different *Anopheles* mosquito species in the study communities

Zone	No of sleepers	*An. gambiae*			*An. coluzzii*			*An. arabiensis*			Total No of *An.* with blood	HBI	MBR (bites/ person/ night)
		No. with blood	HBI	MBR (bites/ person/ night)	No. with blood	HBI	MBR (bites/ person/ night)	No. with blood	HBI	MBR (bites/ person/ night)			
Sudan Savanna													
Bazza	176	6	0.00	0.00	90	0.53	0.27	1	0.00	0.00	97	0.49	0.27
Vimtim	191	11	0.18	0.01	52	0.75	0.20	0	0.00	0.00	63	0.65	0.21
Total	367	17	0.11	0.01	142	0.61	0.24	1	0.00	0.00	160	0.55	0.24
Guinea Savanna													
Imburu	207	62	0.39	0.12	197	0.67	0.64	35	0.63	0.11	294	0.61	0.87
Bachure	212	27	0.59	0.08	109	0.59	0.30	7	0.43	0.01	143	0.59	0.39
Total	419	89	0.45	0.09	306	0.64	0.47	42	0.59	0.06	437	0.59	0.62
Grand Total	**786**	**106**	**0.39**	**0.05**	**448**	**0.63**	**0.36**	**43**	**0.58**	**0.03**	**597**	**0.59**	**0.45**

HBI-human blood index, MBR-man-biting rate.

collected from both zones were found with human blood (Table 4).

In both Sudan and Guinea Savanna communities respectively, sporozoite infection rates were higher among the *An. coluzzii* (2.8%, 8.8%) mosquitoes compared to *An. gambiae* (0%, 2.2%) and *An. arabiensis* (0%, 2.4%) species (Table 6). Sporozoite infection rates of all the mosquitoes collected in the Guinea Savanna (6.9%) communities were 2.9 times higher than those of the Sudan savanna (2.4%) communities (Table 6).

Predominance of *An. coluzzii* species (88.2%, 70%) were observed over *An. gambiae* (10.6%, 20.4%) and *An. arabiensis* (0.6%, 9.6%) in the Sudan and Guinea Savanna zones respectively (Table 6). Higher occurrences of *An. coluzzii* ($\geq$ 67%) compared to *An. gambiae* ($\leq$ 20.9%) and *An. arabiensis* ($\leq$ 15.7%) were evident in each of the four communities (Table 6).

DISCUSSION

This study provides information on species composition and entomological risk indices of *Anopheles* mosquitoes in two vegetation zones within Northeastern Adamawa State, Nigeria. Increased relative humidity between June and August (80% in August) in Adamawa State (Adebayo, 1999) probably resulted in the collection of higher numbers of mosquitoes within this period across the four communities in the two zones of the State. Significantly higher numbers of mosquitoes found in the communities within the Guinea savanna zone is attributable to longer rainy season period and higher annual rainfall compared to the Sudan savanna zone of the State. Annual mean number of female *Anopheles* mosquitoes recorded here in the Guinea Savanna areas of Adamawa State compares with earlier reports (Obembe *et al.*, 2018; Obembe *et al.*, 2019) from Kwara, another Guinea Savanna Nigerian State. Similarities in the numbers of female *Anopheles* mosquitoes collected in the two communities within Sudan Savanna zone of Adamawa State reflects similar climatic conditions in the two communities within the zone. In contrast, significantly higher number of *Anopheles* mosquitoes in Imburu community compared to the Bachure community within the same Guinea Savanna zone could be due to the higher prevalence of irrigated rice mashed areas providing year round breeding sites for mosquitoes in and around Imburu community.

Predominance of *An. coluzzii* over *An. gambiae* in both Guinea and Sudan Savanna communities within Adamawa State is in contrast with the observation of lower *An. coluzzii* incidence in some Savanna regions of Nigeria (Awolola *et al.*, 2005; Obembe *et al.*, 2018). Both *Anopheles coluzzii* and *An. gambiae* mosquito species are known to be naturally anthropophagic and endophilic and therefore considered as very competent vectors in Africa (Gillies and Coetzee 1987; Githeko *et al.*, 1994; Killeen, 2014). However, *An. gambiae* can better utilize small temporary breeding sites (Gimonneau *et al.*, 2014) while *An. coluzzii* prefers flooded relatively permanent breeding sites (Sogoba *et al.*, 2008; Gimonneau *et al.*, 2012). Adamawa State is characterized by flood plains with many rivers passing through the Fadama lands all over the State especially during the rainy season (Adewumi, 2013). These flood plains could have provided the relatively permanent breeding sites preferred by *An. coluzzii* larvae leading to its prevalence over *An. gambiae* and *An. arabiensis* in the four communities considered in this study. Lamidi *et al.* (2017) have also reported the prevalence of *An. coluzzii* in another neighboring Northeastern State of Taraba.

Higher occurrence of *Anopheles coluzzii* among the mosquitoes collected indoors may indicate increased human-vector contact leading to the observations of higher *Anopheles coluzzii* human blood indices, man-biting and sporozoite rates compared to *An. gambiae* and *An. arabiensis*.

Single populations of *An. arabiensis* species typically breed in ephemeral, sunlit water pools (Kenea *et al.*, 2011) and can exhibit a wide range of behaviours, biting and resting indoors as well as outdoors and feeding on both humans and animals (Githeko *et al.*, 1994; Tirados *et al.*, 2006; Kitau *et al.*, 2012; Mayagaya *et al.*, 2015). Therefore, low

Table 6. Species composition and *P. falciparum* Sporozoite infection rates of mosquitoes in the study communities

Zone	Study site	Numbers (%) of different *Anopheles* species identified					†Number (%) of *Anopheles* positive for *P. falciparum* sporozoite infection				
		An. gambiae	*An. coluzzii*	*An. arabiensis*	Hybrid	Number assayed	*An. gambiae*	*An. coluzzii*	*An. arabiensis*	Total no of female *Anopheles*	Total positive
Sudan Savanna	Bazza	6(6)	90(92)	1(1)	1(1)	98(100)	0(0)	2(2.2)	0(0)	100	2(2.0)
	Vimtim	11(17)	52(83)	0(0)	0(0)	63(100)	0(0)	2(3.8)	0(0)	64	2(3.1)
	Total	17(10.6)	142(88.2)	1(0.6)	1(0.6)	161(100)	0(0)	4(2.8)	0(0)	164	4(2.4)
Guinea Savanna	Imburu	62(21)	197(67)	35(12)	0(0)	294(100)	2(3.2)	14(7.1)	1(2.9)	314	17(5.4)
	Bachure	27(19)	109(76)	7(5)	0(0)	143(100)	0(0)	13(11.9)	0(0)	144	13(9.0)
	Total	89(20.4)	306(70)	42(9.6)	0(0)	437(100)	2(2.2)	27(8.8)	1(2.4)	458	30(6.5)
Grand Total		**106(17.7)**	**448(74.9)**	**43(7.2)**	**1(0.2)**	**598(100)**	**2(1.9)**	**31(6.9)**	**1(2.3)**	**622**	**34(5.5)**

† Number of each *Anopheles* species was used as the denominator in calculating the sporozoite rate of such species.

occurrence of indoor resting *An. arabiensis* mosquitoes in this study could also be due to their zoophilic and exophilic tendencies (Mahande *et al*., 2007; Mayagaya *et al*., 2015). This is in consonance with the results of 0.6% *An. arabiensis* incidence in two communities in Guinea Savanna area of Kwara State (Obembe *et al*., 2018). Generally, all the mosquito species had higher numbers in the Guinea savanna compared to the Sudan Savanna zone. However, the difference between the numbers of *An. coluzzii* mosquitoes found in both zones was low compared to the difference between the numbers of mosquitoes of other species (between *An. gambiae* and *An. gambiae*; between *An. arabiensis* and *An. arabiensis*) found in both zones. Lower differences in the number of *An. coluzzii* found in both zones could be as a result of widespread presence of suitable relatively permanent breeding sites (flood plains) available for *An. coluzzii* development in both zones of the State. However, high differences between the numbers of *An. gambiae* in both zones and between the numbers of *An. arabiensis* in both zones is attributable to the higher and longer rainfall resulting in the availability of more small and temporary breeding sites suitable for these two species in the Guinea compared to the Sudan Savanna zone. These high differences in the numbers of *An. gambiae* and *An. arabiensis* between the two zones probably led to the highly different human blood indices of *An. gambiae* and *An. arabiensis* between the two zones. Higher man-biting and *P. falciparum* sporozoite infection rates of *Anopheles* mosquitoes in the communities within the Guinea savanna compared to the Sudan is attributable to the significantly higher *Anopheles* densities found indoors in the former.

Naturally anthropophagic and endophilic *An. coluzzii* species, which had favourable breeding sites within our study area and was the most abundant within the human dwellings, exhibited the highest human blood index (0.63). However this *An. coluzzii* HBI and the overall annual human blood indices of all the *Anopheles* mosquitoes collected in the State (0.59) were lower compared to those reported in other North Eastern States of Gombe (0.71-1.00 (Yoriyo *et al*., 2014) and Borno (0.98 (Samdi, 2012). This results remain puzzling because the lower human blood indices recorded could not have resulted from the use of bed-nets since this was not found in the communities. Also, widespread availability of cattle may not have caused this since *An. coluzzii* are not known to be zoophilic than anthropophilic when both humans and cattle are present. However, indoor insecticide application can induce zoophagic tendencies (Lefevre *et al*., 2009; Ndenga *et al*., 2016) or earlier outdoor biting times (Bayoh *et al*., 2010; Reddy *et al*., 2011; Gatton *et al*., 2013) among previously anthropophagic, endophagic and nocturnal *An. gambiae*, *An. coluzzii* and *An. funestus* species. A common practice found among the community residents in this study area was the use of dried and smoldered leaves and/or freshly hung whole plants as indoor mosquito repellents. As such, a probable reason for the relatively low mosquito human blood indices could be the use of these traditional mosquito repellents driving a sizeable portion of the anthropophilic mosquitoes to subsist on the cattle around the communities. Whether or not this freshly hung or smoldered plants can serve as effective mosquito repellents remains to be investigated. Also, studies on cattle blood indices of the mosquitoes in these areas are required to confirm the subsistence of the mosquitoes on cattle. In addition, studies on the use of improved zooprophylaxis (treating the cattle with recommended doses of appropriate insecticides) could be conducted in these areas to determine the potential of this method in further reducing malaria entomological risk indices in these areas.

This study is limited by the non-collection of outdoor resting mosquitoes in addition to non-determination of cattle blood indices of the indoor resting mosquitoes collected. However, the unavailability and non-utilization of insecticide-treated bed-nets by the community residents, prevalence of cattle as the major animal host within the environment of mosquito collection and non-detection of human blood in about half of the mosquitoes collected, suggest that

the engorged *Anopheles* mosquitoes devoid of human blood could be carrying cattle blood meal.

CONCLUSION

This study revealed variations in entomological risk indices of *Anopheles* mosquitoes in two vegetation zones within a North-Eastern State of Nigeria. Higher entomological risk indices were observed in the Guinea compared to the Sudan Savanna areas of the State. This provides baseline information for prioritization of supplies in the event of scarce mosquito control resources. Studies of this nature are desirable to guide malaria control programmes according to the peculiarities existing in various areas within a State. Prevalence and higher transmission risks indices of endophilic *An. coluzzii* mosquito species reveal the need for integrated malaria vector control management involving the reinforcements of LLIN availability and utilization as well as larval source management of the relatively permanent *An. coluzzii* mosquito breeding sites in the State. Low occurrence of *An. arabiensis* indoors within these cattle dominated areas calls for investigations on outdoor vector species composition and transmission in these areas. Widespread cattle rearing lifestyle as well as lower human blood indices of *Anopheles* mosquitoes in these areas as compared to other savanna areas in Nigeria suggest the need to initiate studies on the cattle blood indices of the mosquitoes in this study area. Such studies may assist in determining the suitability of the use of zooprophylactic malaria risk reduction measures such as insecticide-treated cattle in the study area.

Acknowledgements. The authors wish to thank the community residents for their cooperation throughout the period of the study. We appreciate Drs. Alice and Robert Wirtz of the Centres for Disease Control and Prevention, Atlanta, USA, for supplying the sporozoite ELISA reagents.

Competing interests
None declared.

Authors' contributions
WJA and ATA conceived the study. AOO, ATA and STA designed the study. WJA and AOO supervised the field study and data collection. TAO, MT, WJA and AO conducted the laboratory studies. AO and WJA collated and analyzed the data. AO drafted the manuscript. All authors read and approved the final version of the manuscript.

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