A systematic review and meta-analysis of the human blood index

of the major African malaria vectors

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Abstract

BACKGROUND The proportion of mosquito blood-meals that are of human origin, referred to as the 'human blood index' or HBI, is a key determinant of malaria transmission. We conducted a systematic review of the HBI for the major African malaria vectors.

RESULTS Evidence is presented for higher HBI among *Anopheles gambiae* (M/S forms and *An. coluzzii*/*An. gambiae s.s.* are not distinguished for most studies and therefore combined) as well as *An. funestus* when compared with *An. arabiensis* (prevalence odds ratio adjusted for collection location [i.e. indoor or outdoor]: 1.62; 95%CI 1.09-2.42; 1.84; 95%CI 1.35-2.52, respectively). This finding is keeping with the entomological literature which describes *An. arabiensis* to be more zoophagic than the other major African vectors. However, analysis also revealed that HBI was more associated with location of mosquito captures (R^2=0.29) than with mosquito (sibling) species (R^2=0.11).

CONCLUSIONS Our findings call into question the appropriateness of current methods of assessing host preferences among disease vectors and have important implications for strategizing vector control.

Keywords: blood meal analysis, host preference, mosquito, biting preference, blood index

Background

Malaria is transmitted through mosquito bites, making the vectors' choice of which blood-host species to bite a central component of malaria epidemiology and ecology. In Africa, the majority of infections are transmitted by *Anopheles gambiae* sensu stricto, *An. coluzzii*, *An. funestus* and *An. arabiensis*. Conventional wisdom indicates that the first three vectors are anthropophagic while the latter sibling species is more zoophagic. Levels of anthropophagy/zoophagy are typically assessed using PCR to identify the host species from blood-meals in field-caught mosquitoes, and are then quantified according to the human blood index (HBI), defined as the proportion of blood-meals that are of human origin [1]. Because two mosquito bites on a human are required to complete the malaria parasite's life-cycle, HBI has an inflated impact on metrics of transmission such as the basic reproduction number, the vectorial capacity and the critical density of mosquitoes for sustained transmission [2].

However, the HBI should not be perceived to have a singular, fixed value; all major African malaria vectors have demonstrable plasticity in the host species that they bite [3-5]. It has long been recognised that the same mosquito population will often adjust its biting towards a more locally available host species [1, 6]. This has important implications for malaria control policy. For example, recent studies have observed that increased outdoor biting followed the distribution of insecticide treated bednets [7]. In such circumstances, vector control tools that operate effectively outdoors become a critical component for eliminating local malaria transmission. Unfortunately, the huge malaria burden reduction achieved in the years since 2000 has relied disproportionately on control tools operating indoors [8], and there are limited effective malaria-vector control options for outdoor use.

One technology that shows promise for targeting mosquitoes regardless of whether they bite indoors or outdoors involves the use of systemic insecticides – chemicals applied directly to blood-hosts to kill mosquitoes that take a blood meal. This technology arose from the observation that mosquito mortality was increased following the consumption of sugar-meals [9] or blood-meals [10]

containing ivermectin – a drug used for onchocerciasis control. Drugs approved for veterinary use, such as fipronil, have subsequently been demonstrated to have similar impact when livestock are dosed orally, or when the chemical is applied topically [11]. More recently, systemic insecticides have had durations of their efficacy extended through dosing with higher concentrations [12], combined dosing with adjuvants [13], and with use of sustained-release devices [14]. The stage is set for progress in development and evaluation of ivermectin for vector control [15]. Therefore, we argue that it has never been more important to understand the distribution of malaria-vector bites on alternative host species. Here, we systematically reviewed and meta-analysed the current evidence to identify the factors associated with higher HBI in sub-Saharan Africa.

Methods

Findings from the systematic review were reported following the PRISMA guidelines [16]. The inclusion and exclusion criteria are listed in Table 1 and advanced search terms were developed following initial manual literature searches and a basic PubMed search (Table 2). The purpose of the initial search was to identify keywords and synonyms. The authors agreed on the search terms and inclusion/exclusion criteria before the systematic search was performed. The Ovid database was used to search available MEDLINE and EMBASS literature from inception to February 2018. Books were excluded from all searches as well as articles not written in English. Results were retrieved and collated using Mendeley desktop reference manager.

After eliminating duplications, abstracts for all publications retrieved were reviewed for relevance. Full-text reviews were then conducted on all articles to decide on its inclusion in accordance with the pre-specified inclusion and exclusion criteria. If the inclusion criteria were satisfied the estimated Human Blood Index (HBI) reported was retrieved. Other variables that could have a significant effect on the reported HBI were also retrieved. These variables included (sibling) species (complex), trapping location (indoors, outdoors or both), trap type(s) used and total number of mosquitoes collected. The primary effect measure of interest was the HBI.

The double arcsine square root transformed HBI (expressed as a proportion of all blood-meals) was used to stabilize the variance across the studies [17] and then back transformed for ease of interpretation. A linear model was performed on all eligible studies to gain additional insight into the effect of trapping location and *Anopheles* species on the proportion of HBI. The linear model was fit using the HBI (proportion) as the response variable weighted by the inverse of each study's variance to allow the observations with the least variance to provide the most information to the model, and using robust error variances. All tests were two-tailed and a p-value < 0.05 was deemed statistically significant. Pooled analyses were conducted using MetaXL (version 5.3, EpiGear Int Pty Ltd; Sunrise Beach, Australia) and the regression models were run using Stata MP (version 14, Stata Corp, College Station, TX, USA).

Results

The search identified 1243 potentially relevant studies. After collating these results and reviewing all abstracts, 662 studies were deemed relevant. All full text articles were retrieved, reviewed for relevance and reviewed against all inclusion and exclusion criteria. Sixty-one studies resulting in 166 data points fulfilled all criteria and where included in the analysis. Reason for exclusion at full text stage included inadequate number (fewer than 50) of mosquitoes collected (n=14) and the use of host-biased trapping methodologies (n=4) (Figure 1).

Multiple collection methodologies were identified from the eligible studies. The methodology used was governed by the collection location targeted (indoors or outdoors). Indoor collections were the most widely used (n=118) with pyrethroid spray catch (PSC) the most commonly used methodology (n=78). Other collection methods included manual indoor collections (n=20) and the use of CDC light traps within the household (n=10). Outdoor collections represented 27 of the total data points extracted with manual collection of mosquitoes being the most common collection method (n=13). Pit traps (n= 10) and CDC light traps (n=4) were also an effective collection method. Studies collecting from both indoor and outdoor environments consisted of 21 data points. These studies used a variety of different methods; many used a combination of the most effective indoor and outdoor collection methods. CDC light traps were the most common (n= 12) followed by other combinations of indoor and outdoor methods; CDC light trap plus PSC (n=2) and pit traps and manual indoor collections (n=2) (Table 3 and S1). Collection methods had no significant effect ($p > 0.05$) on the reported HBI when comparing the mean HBI produced by each collection methodology within its respective collection areas (indoor and outdoor) for *An. gambiae, An. arabiensis* and the *An. funestus* species complex (Figure 2). It should be noted that due to the variety of different methods used and therefore sparsity of data for each methodology within the "both" category, a meaningful comparison could not be made.

Meta-regression of the data compiled from the 166 data points demonstrated a significantly higher proportion of blood-meals were of human origin (the human blood index, 'HBI') among *An*.

funestus (prevalence odds ratios [POR] of 1.84 (95%CI 1.35-2.52, p<0.001) and *An*. *gambiae* (POR of 1.62, 95%CI 1.09-2.52, p=0.02) compared to *An*. *arabiensis*. The majority of studies including details of *An*. *gambiae* did not specify whether they were M or S forms (or, in more modern nomenclature, *An. coluzzii* or *An. gambiae s.s.*), so these were combined. For all three groups, a significantly higher HBI was found from indoor mosquito collections (POR of 2.74, 95%CI 2.00-3.75, p<0.001) as well as combined indoor and outdoor collections (POR of 4.20, 95%CI 3.13-5.62, p<0.001) versus outdoor only collections. The results also revealed that trapping location (R^2 of 0.29) had a larger impact on the blood-meal host species than mosquito species (or species complex) (R^2 of 0.11) and that this difference was statistically significant (p<0.01 resulting from an F-test comparing both univariate models) (Table 4).

Discussion

Control of vector-borne diseases is largely, often entirely, dependent on vector control. For malaria, vector control is achieved primarily through targeting mosquitoes that are host-seeking [8]. The major African malaria vectors, *An. gambiae s.s.*, *An. coluzzii* and *An. funestus*, are regularly cited as paragons of anthropophagy, and any non-human biting exhibited by these species has historically been ignored when strategizing control. Here, their biting behaviour was systematically reviewed for the first time and it was demonstrated that the difference in their host choice compared with the zoophilic vector *An. arabiensis* was dwarfed by the difference found when comparing indoor with outdoor collections. In other words, *where* the mosquito was collected was substantially and significantly more influential on host choice than *which* mosquito species was collected.

This raises an important question: where should vectors be collected from in order to provide the most useful HBI estimates? Our results indicate that a single HBI for a given location risks presenting quite a biased estimate for local vector biting behaviour. A standardised HBI accounting for both indoor and outdoor behaviours would probably constitute an invalid metric because of the increased difficulty posed by collecting blood-fed mosquitoes outdoors i.e., we lack the tools to estimate indoor versus outdoor mosquito numbers with any confidence. Therefore, our recommendation is to present both estimates for an indoor HBI and an outdoor HBI. Longitudinal assessments initiated before rolling out control tools, and followed up over the time course of the programme would provide a valuable source of information. For example, these would determine the timeframe across which LLIN-derived exophagy [7] occurs, as well as provide unbiased estimates of the magnitude of effect. These entomological data would also be able to inform on whether there is a reversion to behavioural norm after a certain period post-distribution, and the rate at which this occurred.

Better data on this behaviour and its temporality will do much more than inform a fundamental aspect of mosquito ecology: it will have considerable ramifications pertaining to malaria

control. For example, if significantly reduced HBI is detected immediately following the distribution of LLINs, this may present an excellent opportunity to synergise bednets with systemic insecticide-treated livestock. Saul [18] described the potential for zooprophylaxis to switch into zoopotentiation if the availability of alternative blood meals increases mosquito survival more than counters the impact of diverting feeds. This risk could be reduced or eliminated with systemic insecticidal dosing that is judiciously timed with LLIN roll-out. Mathematical models already exist for optimal systemic insecticide deployment [19] including its integration with LLINs [20]. These could immediately be capitalised upon once the temporal HBI data became available.

One further, important unknown pertaining to HBI is the spatial scale across which within-mosquito population plasticity occurs. Over 50 years ago, Garrett-Jones described differing HBI estimates for mosquitoes collected from proximal locations [1]. Given the current concerns over altered biting behaviour potentially compromising recent gains in malaria burden reduction [21], a fuller comprehension of the scale and magnitude of this variability is timely. A recent study conducted in southern Ghana describes the successful piloting of a novel experimental design to address exactly this phenomenon [22]. It demonstrated that statistically significant alteration in host choice for *An. coluzzii* was detectable over a range of 250 metres [22]. Heterogeneity in mosquito biting rates has been demonstrated to be key to malaria transmission, first by theoretical work [23], but more recently with empirical studies using genotyping of blood-meals [24]. Future modelling frameworks will need to account for this additional form of village-level heterogeneity in biting behaviour.

To summarise, we presented the first systematic review of the HBI of the major African malaria vectors. We demonstrated that where mosquitoes are collected from (indoors versus outdoors) is significantly more associated with the HBI than which mosquito (sibling) species is collected. Some of the more important consequences to disease control of this behaviour are described. We further highlight some new theoretical and empirical developments that may improve both HBI assessment and how this metric can inform malaria control optimisation.

Declarations

Ethics approval and consent to participate Not applicable

Consent for publication Not applicable

Availability of data and material All data generated or analysed during this study are included in this published article [and its supplementary information files].

Competing interests The authors declare that they have no competing interests

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Authors' contributions LY conceived the study. JO, LFK and LY performed the systematic review and meta-analysis. All authors contributed to results interpretation and manuscript drafting.

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Table 1. Inclusion and exclusion criteria for systematic review

Inclusion Criteria	**Exclusion Criteria**
Studies which used blood meal analysis (PCR,ELISA or precipitin tests) to report the HBI	Semi field studies, studies using baited traps or choice experiments to investigate host preference
Studies performed in sub-Saharan Africa	Entomological studies not specifically reporting the HBI
Studies reporting the HBI for individual mosquito species	Studies not reporting total number of mosquitoes caught
Reporting HBI for *Anopheles gambiae, Anopheles funestus complex* or *Anopheles arabiensis* mosquito species	Data points based on less than 50 blood-fed mosquitoes in total for target species
Studies reporting trapping methodology including location of traps (indoors or outdoors)	

Table 2. Search strategy for systematic review

Ovid MEDLINE® Database
Human blood index **OR** HBI **OR** host preference **OR** trophic preference **OR** blood meal preference **OR** blood host preference **OR** blood meal **OR** blood meal analysis **OR** blood-meal analysis **OR** blood meal source **OR** host blood **OR** host blood meal **OR** blood meal identification [multiple posting= MeSH subject heading word ,abstract, title, original title, text word (title, abstract), key word heading, name of substance, key word heading word, protocol supplementary concept word, synonym]
AND
Anopheles **OR** Anopheles arabiensis **OR** Anopheles gambiae **OR** Anopheles funestus [multiple posting= MeSH subject heading word ,abstract, title, original title, text word (title, abstract), key word heading, name of substance, key word heading word, protocol supplementary concept word, synonym]

Table 3. Data points extracted from eligible studies for each collection location and trapping methodology

The top three methodologies based on number of data points extracted are displayed here

				Methodology								
	Collection Location			Indoor			Outdoor			Both (Indoor + Outdoor)		
Species	Indoor	Outdoor	Both	Pyrethroid Spray Catch (PSC)	Manual aspiration	CDC light trap	Manual aspiration	CDC Light trap	Pit Traps	CDC light trap + PSC	CDC light trap	Others
Anopheles gambiae	37	7	3	22	10	2	7	0	0	1	0	2
Anopheles arabiensis	50	14	10	39	2	7	1	4	9	0	10	0
Anopheles funestus s.l.	31	6	8	17	8	1	5	0	1	1	2	5

Table 4. Predictors of Human Blood Index: univariate and multivariate regression models

Predictors	Univariate		Multivariate	
	POR (95% CI)	R^2	POR (95% CI)	R^2
Anopheles species		0.11		0.40
An. arabiensis	1.00		1.00	
*An. gambiae**	1.50 (0.95-2.36)		1.62 (1.09-2.42)	
An. funestus	1.95 (1.34-2.85)		1.84 (1.35-2.52)	
Location		0.29		
Outdoor only	1.00		1.00	
Indoor only	2.83 (2.04-3.93)		2.74 (2.00-3.75)	
Both	3.98 (3.14-5.06)		4.20 (3.13-5.62)	

POR, prevalence odds ratio; *most studies did not specify M/S form of *An. gambiae* (and pre-dated the renaming of these forms as *An. coluzzii* and *An. gambiae s.s.* respectively).

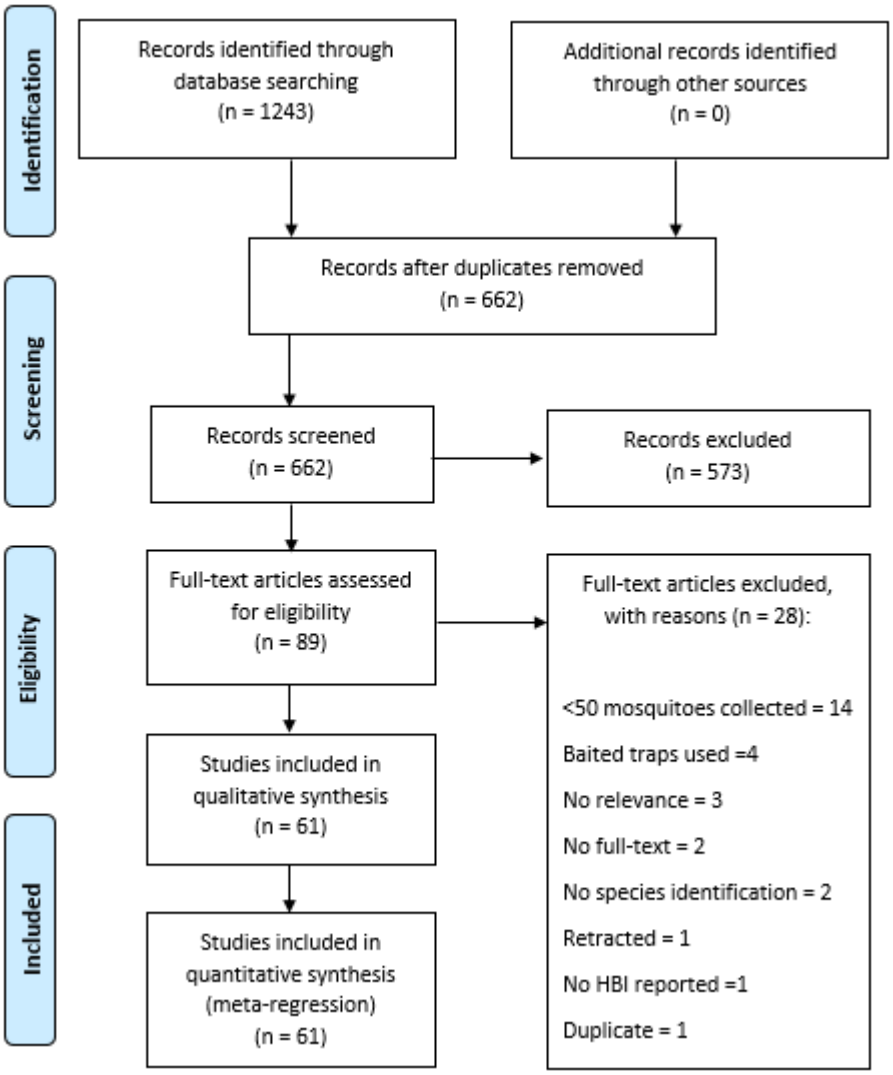

Figure 1. PRISMA flow diagram of search phases with numbers of studies included/excluded at each stage.

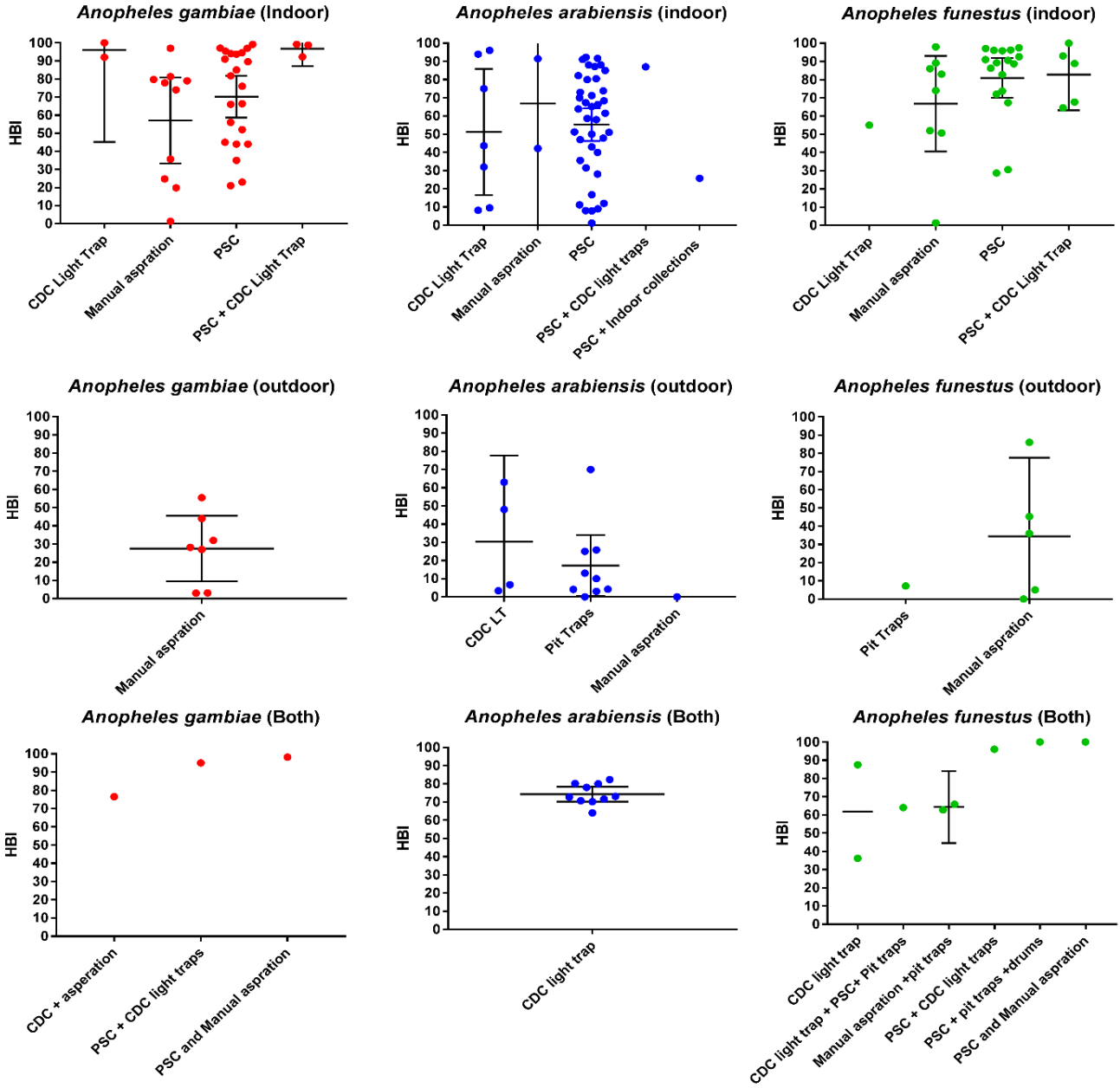

Figure 2: Reported mean HBI (+95% CIs) for individual collection methods when sampling from indoor, outdoor or both (indoor and outdoor) environments for *An. gambiae, An. arabiensis* and *An. funestus*.

Table S1: All eligible studies (and corresponding data points) retrieved from systematic search

Lead Author	Year Published	Reference	Location	Species	collection area (indoor/outdoor/both)	collection method	human blood	Total number of bloodfeds analysed/caught
Das	2017	Beyond the entomological inoculation rate: characterizing multiple blood feeding behavior and *Plasmodium falciparum* multiplicity of infection in *Anopheles* mosquitoes in northern Zambia	Zambia	*Anopheles funestus complex*	Both	PSC + CDC	426	444
Das	2017	Beyond the entomological inoculation rate: characterizing multiple blood feeding behavior and *Plasmodium falciparum* multiplicity of infection in *Anopheles* mosquitoes in northern Zambia	Zambia	*Anopheles gambiae*	Both	PSC + CDC	95	100
Ogola	2017	Composition of Anopheles mosquitoes, their blood-meal hosts, and Plasmodium falciparum infection rates in three islands with disparate bed net coverage in Lake Victoria, Kenya.	Kenya	*Anopheles gambiae*	Both	CDC + outdoor manual collections	236	310
Degefa	2017	Indoor and outdoor malaria vector surveillance in western Kenya: implications for better understanding of residual transmission	Kenya	*Anopheles arabiensis*	Indoors	CDC	10	122
Degefa	2017	Indoor and outdoor malaria vector surveillance in western Kenya: implications for better understanding of residual transmission	Kenya	*Anopheles arabiensis*	Indoors	PSC	1	165
Degefa	2017	Indoor and outdoor malaria vector surveillance in western Kenya: implications for better understanding of residual transmission	Kenya	*Anopheles arabiensis*	Outdoors	CDC	2	59
Degefa	2017	Indoor and outdoor malaria vector surveillance in western Kenya:	Kenya	*Anopheles arabiensis*	Outdoors	Pit traps	208	298

		implications for better understanding of residual transmission						
Kibret	2017	Malaria impact of large dams at different eco-epidemiological settings in Ethiopia	Ethopia	*Anopheles arabiensis*	Both	CDC	761	924
Kibret	2017	Malaria impact of large dams at different eco-epidemiological settings in Ethiopia	Ethopia	*Anopheles arabiensis*	Both	CDC	202	278
Kibret	2017	Malaria impact of large dams at different eco-epidemiological settings in Ethiopia	Ethopia	*Anopheles arabiensis*	Both	CDC	277	392
Kibret	2017	Malaria impact of large dams at different eco-epidemiological settings in Ethiopia	Ethopia	*Anopheles arabiensis*	Both	CDC	117	168
Kibret	2017	Malaria impact of large dams at different eco-epidemiological settings in Ethiopia	Ethopia	*Anopheles funestus complex*	Both	CDC	272	311
Kabula	2016	A significant association between deltamethrin resistance, Plasmodium falciparum infection and the Vgsc-1014S resistance mutation in Anopheles gambiae highlights the epidemiological importance of resistance markers	Tanzania	*Anopheles gambiae*	Indoors	PSC	548	575
Kabula	2016	A significant association between deltamethrin resistance, Plasmodium falciparum infection and the Vgsc-1014S resistance mutation in Anopheles gambiae highlights the epidemiological importance of resistance markers	Tanzania	*Anopheles arabiensis*	Indoors	PSC	409	575
Sande	2016	Biting behaviour of Anopheles funestus populations in Mutare and Mutasa districts, Manicaland province, Zimbabwe: Implications for the malaria control programme	Zimbabwe	*Anopheles funestus complex*	Both	CDC,PSC and Pit traps	174	272
Chirebvu	2016	Characterization of an Indoor-Resting Population of Anopheles arabiensis (Diptera: Culicidae) and the Implications on Malaria Transmission in Tubu Village in Okavango Subdistrict, Botswana.	Botswana	*Anopheles arabiensis*	Indoors	PSC + Indoor manual collections	35	139

Lekweiry	2016	Circumsporozoite protein rates, blood-feeding pattern and frequency of knockdown resistance mutations in *Anopheles* spp. in two ecological zones of Mauritania	Mauritania	*Anopheles arabiensis*	Indoors	PSC	46	80
Ndiath	2016	Composition and genetics of malaria vector populations in the Central African Republic	Central African Republic	*Anopheles gambiae*	Indoors	PSC	121	149
Lozano-Fuentes	2016	Evaluation of a topical formulation of eprinomectin against *Anopheles arabiensis* when administered to Zebu cattle (*Bos indicus*) under field conditions	kenya	*Anopheles arabiensis*	Indoors	PSC	10	131
Lozano-Fuentes	2016	Evaluation of a topical formulation of eprinomectin against *Anopheles arabiensis* when administered to Zebu cattle (*Bos indicus*) under field conditions	kenya	*Anopheles gambiae*	Indoors	PSC	77	91
Mosqueira	2015	Pilot study on the combination of an organophosphate-based insecticide paint and pyrethroid-treated long lasting nets against pyrethroid resistant malaria vectors in Burkina Faso.	Burkina Faso	*Anopheles gambiae*	Indoors	Indoor manual collection	34	141
Mosqueira	2015	Pilot study on the combination of an organophosphate-based insecticide paint and pyrethroid-treated long lasting nets against pyrethroid resistant malaria vectors in Burkina Faso.	Burkina Faso	*Anopheles gambiae*	Indoors	Indoor manual collection	51	143
Mosqueira	2015	Pilot study on the combination of an organophosphate-based insecticide paint and pyrethroid-treated long lasting nets against pyrethroid resistant malaria vectors in Burkina Faso.	Burkina Faso	*Anopheles gambiae*	Indoors	Indoor manual collection	28	141
Das	2015	Underestimation of foraging behaviour by standard field methods in malaria vector mosquitoes in southern Africa.	Zambia and Zimbabwe	*Anopheles arabiensis*	Indoors	PSC + CDC	559	643

Das	2015	Underestimation of foraging behaviour by standard field methods in malaria vector mosquitoes in southern Africa.	Zambia and Zimbabwe	*Anopheles funestus complex*	Indoors	PSC + CDC	343	343
Das	2015	Underestimation of foraging behaviour by standard field methods in malaria vector mosquitoes in southern Africa.	Zambia and Zimbabwe	*Anopheles funestus complex*	Indoors	PSC + CDC	78	84
Massebo	2015	Zoophagic behaviour of anopheline mosquitoes in southwest Ethiopia: opportunity for malaria vector control	Ethopia	*Anopheles arabiensis*	Indoors	CDC	93	988
Massebo	2015	Zoophagic behaviour of anopheline mosquitoes in southwest Ethiopia: opportunity for malaria vector control	Ethopia	*Anopheles arabiensis*	Indoors	PSC	59	352
Massebo	2015	Zoophagic behaviour of anopheline mosquitoes in southwest Ethiopia: opportunity for malaria vector control	Ethopia	*Anopheles arabiensis*	Outdoors	Pit traps	26	894
Guelbeogo	2014	Behavioural divergence of sympatric Anopheles funestus populations in Burkina Faso.	Burkina Faso	*Anopheles funestus complex*	Indoors	PSC	211	221
Guelbeogo	2014	Behavioural divergence of sympatric Anopheles funestus populations in Burkina Faso.	Burkina Faso	*Anopheles funestus complex*	Indoors	PSC	242	272
Guelbeogo	2014	Behavioural divergence of sympatric Anopheles funestus populations in Burkina Faso.	Burkina Faso	*Anopheles funestus complex*	Outdoors	Pit traps	38	529
Sougoufara	2014	Biting by *Anopheles funestus* in broad daylight after use of long-lasting insecticidal nets: a new challenge to malaria elimination	Senigal	*Anopheles funestus complex*	Indoors	PSC	61	84
Antonio-Nkondjio	2014	High malaria transmission intensity in a village close to Yaounde, the capital city of Cameroon.	Cameroon	*Anopheles funestus complex*	Both	PSC + pit traps +drums	299	299
Kibret	2014	Increased malaria transmission around irrigation schemes in Ethiopia and the potential of canal water management for malaria vector control	Ethopia	*Anopheles funestus complex*	Both	CDC	20	58

Kibret	2014	Increased malaria transmission around irrigation schemes in Ethiopia and the potential of canal water management for malaria vector control	Ethopia	*Anopheles arabiensis*	Both	CDC	1680	2101
Kibret	2014	Increased malaria transmission around irrigation schemes in Ethiopia and the potential of canal water management for malaria vector control	Ethopia	*Anopheles arabiensis*	Both	CDC	171	234
McCann	2014	Reemergence of Anopheles funestus as a Vector of Plasmodium falciparum in Western Kenya after Long-Term Implementation of Insecticide-Treated Bed Nets	Kenya	*Anopheles funestus complex*	Indoors	PSC	697	715
McCann	2014	Reemergence of Anopheles funestus as a Vector of Plasmodium falciparum in Western Kenya after Long-Term Implementation of Insecticide-Treated Bed Nets	Kenya	*Anopheles arabiensis*	Indoors	PSC	58	115
McCann	2014	Reemergence of Anopheles funestus as a Vector of Plasmodium falciparum in Western Kenya after Long-Term Implementation of Insecticide-Treated Bed Nets	Kenya	*Anopheles gambiae*	Indoors	PSC	51	55
McCann	2014	Reemergence of Anopheles funestus as a Vector of Plasmodium falciparum in Western Kenya after Long-Term Implementation of Insecticide-Treated Bed Nets	Kenya	Anopheles arabiensis	Indoors	PSC	25	73
Massebo	2013	Blood meal origins and insecticide susceptibility of *Anopheles arabiensis* from Chano in South-West Ethiopia	Ethopia	*Anopheles arabiensis*	Indoors	CDC	741	988
Massebo	2013	Blood meal origins and insecticide susceptibility of *Anopheles arabiensis* from Chano in South-West Ethiopia	Ethopia	*Anopheles arabiensis*	Indoors	PSC	204	352

Massebo	2013	Blood meal origins and insecticide susceptibility of *Anopheles arabiensis* from Chano in South-West Ethiopia	Ethopia	*Anopheles arabiensis*	Outdoors	Pit traps	116	894
Animut	2013	Blood meal sources and entomological inoculation rates of anophelines along a highland altitudinal transect in south-central Ethiopia	Ethopia	*Anopheles arabiensis*	Indoors	CDC	135	422
Animut	2013	Blood meal sources and entomological inoculation rates of anophelines along a highland altitudinal transect in south-central Ethiopia	Ethopia	*Anopheles arabiensis*	Outdoors	PSC	227	723
Animut	2013	Blood meal sources and entomological inoculation rates of anophelines along a highland altitudinal transect in south-central Ethiopia	Ethopia	*Anopheles arabiensis*	Indoors	CDC	27	64
Animut	2013	Blood meal sources and entomological inoculation rates of anophelines along a highland altitudinal transect in south-central Ethiopia	Ethopia	*Anopheles arabiensis*	Outdoors	PSC	32	114
Dadzie	2013	Role of species composition in malaria transmission by the *Anopheles funestus* group (Diptera: Culicidae) in Ghana	Ghana	*Anopheles funestus complex*	Indoors	PSC	80	89
Dadzie	2013	Role of species composition in malaria transmission by the *Anopheles funestus* group (Diptera: Culicidae) in Ghana	Ghana	*Anopheles funestus complex*	Indoors	PSC	52	64
Dadzie	2013	Role of species composition in malaria transmission by the *Anopheles funestus* group (Diptera: Culicidae) in Ghana	Ghana	*Anopheles funestus complex*	Indoors	PSC	73	76
Obala	2012	Anopheles gambiae and Anopheles arabiensis population densities and infectivity in Kopere village, Western Kenya	Kenya	*Anopheles arabiensis*	Indoors	PSC	59	68

Obala	2012	Anopheles gambiae and Anopheles arabiensis population densities and infectivity in Kopere village, Western Kenya	Kenya	*Anopheles gambiae*	Indoors	PSC	198	205
Mzilahowa	2012	Entomological indices of malaria transmission in Chikhwawa district, Southern Malawi	Malawi	*Anopheles funestus complex*	Indoors	PSC	286	297
Mzilahowa	2012	Entomological indices of malaria transmission in Chikhwawa district, Southern Malawi	Malawi	*Anopheles gambiae*	Indoors	PSC	244	246
Mzilahowa	2012	Entomological indices of malaria transmission in Chikhwawa district, Southern Malawi	Malawi	*Anopheles arabiensis*	Indoors	PSC	289	340
Kibret	2012	How does an Ethiopian dam increase malaria? Entomological determinants around the Koka reservoir.	Ethopia	*Anopheles arabiensis*	Both	CDC	148	208
Kibret	2012	How does an Ethiopian dam increase malaria? Entomological determinants around the Koka reservoir.	Ethopia	*Anopheles arabiensis*	Both	CDC	89	111
Kibret	2012	How does an Ethiopian dam increase malaria? Entomological determinants around the Koka reservoir.	Ethopia	*Anopheles arabiensis*	Both	CDC	56	89
Kawada	2012	Reconsideration of *Anopheles rivulorum* as a vector of *Plasmodium falciparum* in western Kenya: some evidence from biting time, blood preference, sporozoite positive rate, and pyrethroid resistance	Kenya	*Anopheles funestus complex*	Indoors	Indoor manual collection	34	69
Tanga	2011	Daily survival and human blood index of major malaria vectors associated with oil palm cultivation in Cameroon and their role in malaria transmission.	Cameroon	*Anopheles funestus complex*	Indoors	PSC	237	245
Himeidan	2011	Pattern of malaria transmission along the Rahad River basin, Eastern Sudan	Sudan	*Anopheles arabiensis*	Indoors	PSC	176	219
Himeidan	2011	Pattern of malaria transmission along the Rahad River basin, Eastern Sudan	Sudan	*Anopheles arabiensis*	Indoors	PSC	68	102

Himeidan	2011	Pattern of malaria transmission along the Rahad River basin, Eastern Sudan	Sudan	*Anopheles arabiensis*	Indoors	PSC	37	58
Himeidan	2011	Pattern of malaria transmission along the Rahad River basin, Eastern Sudan	Sudan	*Anopheles arabiensis*	Indoors	PSC	361	394
Himeidan	2011	Pattern of malaria transmission along the Rahad River basin, Eastern Sudan	Sudan	*Anopheles arabiensis*	Indoors	PSC	95	119
Himeidan	2011	Pattern of malaria transmission along the Rahad River basin, Eastern Sudan	Sudan	*Anopheles arabiensis*	Indoors	PSC	39	64
Himeidan	2011	Pattern of malaria transmission along the Rahad River basin, Eastern Sudan	Sudan	*Anopheles arabiensis*	Indoors	PSC	272	331
Mala	2011	Plasmodium falciparum transmission and aridity: a Kenyan experience from the dry lands of Baringo and its implications for Anopheles arabiensis control	Kenya	*Anopheles arabiensis*	Outdoors	CDC	55	88
Mala	2011	Plasmodium falciparum transmission and aridity: a Kenyan experience from the dry lands of Baringo and its implications for Anopheles arabiensis control	Kenya	*Anopheles arabiensis*	Indoors	PSC	58	136
Mala	2011	Plasmodium falciparum transmission and aridity: a Kenyan experience from the dry lands of Baringo and its implications for Anopheles arabiensis control	Kenya	*Anopheles arabiensis*	Outdoors	CDC	71	149
Fornadel	2010	Analysis of Anopheles arabiensis Blood Feeding Behavior in Southern Zambia during the Two Years after Introduction of Insecticide-Treated Bed Nets	Zambia	*Anopheles arabiensis*	Indoors	CDC	220	235
Fornadel	2010	Analysis of Anopheles arabiensis Blood Feeding Behavior in Southern Zambia during the Two Years after Introduction of Insecticide-Treated Bed Nets	Zambia	*Anopheles arabiensis*	Indoors	CDC	223	233
Tchuinkam	2010	Bionomics of Anopheline species and malaria transmission dynamics along an altitudinal transect in Western Cameroon.	Cameroon	*Anopheles gambiae*	Indoors	PSC	269	278
Tchuinkam	2010	Bionomics of Anopheline species and malaria transmission dynamics along an altitudinal transect in Western Cameroon.	Cameroon	*Anopheles gambiae*	Indoors	PSC	68	77

Tchuinkam	2010	Bionomics of Anopheline species and malaria transmission dynamics along an altitudinal transect in Western Cameroon.	Cameroon	*Anopheles gambiae*	Indoors	PSC	347	371
Tanga	2010	Climate change and altitudinal structuring of malaria vectors in south-western Cameroon: their relation to malaria transmission	Cameroon	*Anopheles gambiae*	Both	PSC and outdoor manual collections	109	112
Tanga	2010	Climate change and altitudinal structuring of malaria vectors in south-western Cameroon: their relation to malaria transmission	Cameroon	*Anopheles funestus complex*	Both	PSC and outdoor manual collections	63	63
Adeleke	2010	Population dynamics of indoor sampled mosquitoes and their implication in disease transmission in Abeokuta, south-western Nigeria	Nigeria	*Anopheles gambiae*	Indoors	CDC	225	225
Kibret	2010	The impact of a small-scale irrigation scheme on malaria transmission in Ziway area, Central Ethiopia.	Ethopia	*Anopheles arabiensis*	Both	CDC	93	120
Kasili	2009	Entomological assessment of the potential for malaria transmission in Kibera slum of Nairobi, Kenya	Kenya	*Anopheles gambiae*	Indoors	Indoor manual collection	77	80
Kerah-Hinzoumbé	2009	Malaria vectors and transmission dynamics in Goulmoun, a rural city in south-western Chad	Chad	*Anopheles arabiensis*	Indoors	PSC	92	144
Kerah-Hinzoumbé	2009	Malaria vectors and transmission dynamics in Goulmoun, a rural city in south-western Chad	Chad	*Anopheles funestus complex*	Indoors	PSC	48	53
Caputo	2008	*Anopheles gambiae complex along The Gambia river, with particular reference to the molecular forms of An. gambiae s.s*	Gambia	*Anopheles gambiae*	Indoors	PSC	36	56
Caputo	2008	*Anopheles gambiae complex along The Gambia river, with particular reference to the molecular forms of An. gambiae s.s*	Gambia	*Anopheles gambiae*	Indoors	PSC	71	158
Caputo	2008	*Anopheles gambiae complex along The Gambia river, with particular reference to the molecular forms of An. gambiae s.s*	Gambia	*Anopheles gambiae*	Indoors	PSC	16	73

Caputo	2008	*Anopheles gambiae complex along The Gambia river, with particular reference to the molecular forms of An. gambiae s.s*	Gambia	*Anopheles gambiae*	Indoors	PSC	36	82
Caputo	2008	*Anopheles gambiae complex along The Gambia river, with particular reference to the molecular forms of An. gambiae s.s*	Gambia	*Anopheles gambiae*	Indoors	PSC	29	68
Caputo	2008	*Anopheles gambiae complex along The Gambia river, with particular reference to the molecular forms of An. gambiae s.s*	Gambia	*Anopheles gambiae*	Indoors	PSC	18	89
Caputo	2008	*Anopheles gambiae complex along The Gambia river, with particular reference to the molecular forms of An. gambiae s.s*	Gambia	*Anopheles gambiae*	Indoors	PSC	51	68
Caputo	2008	*Anopheles gambiae complex along The Gambia river, with particular reference to the molecular forms of An. gambiae s.s*	Gambia	*Anopheles gambiae*	Indoors	PSC	62	179
Muturi	2008	Effect of Rice Cultivation on Malaria Transmission in Central Kenya	kenya	*Anopheles arabiensis*	Indoors	PSC	73	812
Muturi	2008	Effect of Rice Cultivation on Malaria Transmission in Central Kenya	kenya	*Anopheles arabiensis*	Indoors	PSC	40	334
Muturi	2008	Effect of Rice Cultivation on Malaria Transmission in Central Kenya	kenya	*Anopheles arabiensis*	Indoors	PSC	65	131
Muturi	2008	Effect of Rice Cultivation on Malaria Transmission in Central Kenya	kenya	*Anopheles funestus complex*	Indoors	PSC	46	65
Fornadel	2008	Increased Endophily by the Malaria Vector Anopheles arabiensis in Southern Zambia and Identification of Digested Blood Meals	zambia	*Anopheles arabiensis*	Indoors	PSC	252	289
Abdalla	2008	Insecticide susceptibility and vector status of natural populations of *Anopheles arabiensis* from Sudan	Sudan	*Anopheles arabiensis*	Indoors	PSC	273	310
Kweka	2008	Mosquito abundance, bed net coverage and other factors associated with variations in sporozoite infectivity rates in four villages of rural Tanzania	Tanzania	*Anopheles funestus complex*	Indoors	PSC	719	811
Kweka	2008	Mosquito abundance, bed net coverage and other factors associated with	Tanzania	*Anopheles arabiensis*	Indoors	PSC	81	727

		variations in sporozoite infectivity rates in four villages of rural Tanzania						
Kweka	2008	Vector species composition and malaria infectivity rates in Mkuzi, Muheza District, north-eastern Tanzania	Tanzania	*Anopheles gambiae*	Indoors	PSC + CDC	1129	1224
Kweka	2008	Vector species composition and malaria infectivity rates in Mkuzi, Muheza District, north-eastern Tanzania	Tanzania	*Anopheles funestus complex*	Indoors	PSC + CDC	251	283
Kweka	2008	Vector species composition and malaria infectivity rates in Mkuzi, Muheza District, north-eastern Tanzania	Tanzania	*Anopheles funestus complex*	Indoors	PSC + CDC	51	80
Kweka	2008	Vector species composition and malaria infectivity rates in Mkuzi, Muheza District, north-eastern Tanzania	Tanzania	*Anopheles funestus complex*	Indoors	PSC + CDC	33	50
Mahande	2007	Feeding and resting behaviour of malaria vector, Anopheles arabiensis with reference to zooprophylaxis.	Tanzania	*Anopheles arabiensis*	Indoors	PSC	166	417
Mahande	2007	Feeding and resting behaviour of malaria vector, Anopheles arabiensis with reference to zooprophylaxis.	Tanzania	*Anopheles arabiensis*	Outdoors	Pit traps	0	417
Mahande	2007	Feeding and resting behaviour of malaria vector, Anopheles arabiensis with reference to zooprophylaxis.	Tanzania	*Anopheles arabiensis*	Indoors	PSC	291	417
Mahande	2007	Feeding and resting behaviour of malaria vector, Anopheles arabiensis with reference to zooprophylaxis.	Tanzania	*Anopheles arabiensis*	Outdoors	Pit traps	41	417
Muriu	2007	Host choice and multiple blood feeding behaviour of malaria vectors and other anophelines in Mwea rice scheme, Kenya	Kenya	*Anopheles arabiensis*	Indoors	PSC	194	2467
Muriu	2007	Host choice and multiple blood feeding behaviour of malaria vectors and other anophelines in Mwea rice scheme, Kenya	Kenya	*Anopheles arabiensis*	Outdoors	CDC	5	75
Muriu	2007	Host choice and multiple blood feeding behaviour of malaria vectors and other anophelines in Mwea rice scheme, Kenya	Kenya	*Anopheles funestus complex*	Indoors	PSC	51	181

Temu	2007	Identification of four members of the *Anopheles funestus*(Diptera: Culicidae) group and their role in *Plasmodium falciparum* transmission in Bagamoyo coastal Tanzania	Tanzania	*Anopheles funestus complex*	Indoors	CDC	66	120
Kent	2007	Seasonality, blood feeding behavior, and transmission of Plasmodium falciparum by Anopheles arabiensis after an extended drought in southern Zambia.	zambia	*Anopheles arabiensis*	Indoors	PSC	415	450
Kulkarni	2006	Entomological Evaluation of Malaria Vectors at Different Altitudes in Hai District, Northeastern Tanzania	Tanzania	*Anopheles arabiensis*	Indoors	PSC	668	905
Kulkarni	2006	Entomological Evaluation of Malaria Vectors at Different Altitudes in Hai District, Northeastern Tanzania	Tanzania	*Anopheles arabiensis*	Outdoors	Pit traps	36	144
Kulkarni	2006	Entomological Evaluation of Malaria Vectors at Different Altitudes in Hai District, Northeastern Tanzania	Tanzania	*Anopheles funestus complex*	Indoors	PSC	57	86
Yohannes	2005	Can source reduction of mosquito larval habitat reduce malaria transmission in Tigray, Ethiopia?	Ethopia	*Anopheles arabiensis*	Indoors	PSC	141	194
Awolola	2005	Identification of three members of the Anopheles funestus (Diptera: Culicidae) group and their role in malaria transmission in two ecological zones in Nigeria	Nigeria	*Anopheles funestus complex*	Both	Indoor manual collections +pit traps	173	264
Awolola	2005	Identification of three members of the Anopheles funestus (Diptera: Culicidae) group and their role in malaria transmission in two ecological zones in Nigeria	Nigeria	*Anopheles funestus complex*	Both	Indoor manual collections +pit traps	187	299
Kamau	2003	Anopheles parensis: the main member of the Anopheles funestus species group found resting inside human dwellings in Mwea area of central Kenya toward the end of the rainy season.	Kenya	*Anopheles funestus complex*	Indoors	Indoor manual collection	2	139

Wanji	2003	Anopheles species of the mount Cameroon region: biting habits, feeding behaviour and entomological inoculation rates.	Cameroon	*Anopheles gambiae*	Indoors	PSC	156	235
Wanji	2003	Anopheles species of the mount Cameroon region: biting habits, feeding behaviour and entomological inoculation rates.	Cameroon	*Anopheles funestus complex*	Indoors	PSC	72	235
Mwangangi	2003	Blood-meal analysis for anopheline mosquitoes sampled along the Kenyan coast.	Kenya	*Anopheles gambiae*	Indoors	PSC	307	338
Mwangangi	2003	Blood-meal analysis for anopheline mosquitoes sampled along the Kenyan coast.	Kenya	*Anopheles arabiensis*	Indoors	PSC	72	79
Mwangangi	2003	Blood-meal analysis for anopheline mosquitoes sampled along the Kenyan coast.	Kenya	*Anopheles funestus complex*	Indoors	PSC	378	439
Ijumba	2002	Malaria transmission risk variations derived from different agricultural practices in an irrigated area of northern Tanzania.	Tanzania	*Anopheles arabiensis*	Indoors	PSC	380	795
Ijumba	2002	Malaria transmission risk variations derived from different agricultural practices in an irrigated area of northern Tanzania.	Tanzania	*Anopheles arabiensis*	Indoors	PSC	132	193
Ijumba	2002	Malaria transmission risk variations derived from different agricultural practices in an irrigated area of northern Tanzania.	Tanzania	*Anopheles arabiensis*	Indoors	PSC	160	241
Ijumba	2002	Malaria transmission risk variations derived from different agricultural practices in an irrigated area of northern Tanzania.	Tanzania	*Anopheles arabiensis*	Outdoors	Pit traps	21	501
Ijumba	2002	Malaria transmission risk variations derived from different agricultural	Tanzania	*Anopheles arabiensis*	Outdoors	Pit traps	44	174

		practices in an irrigated area of northern Tanzania.						
Ijumba	2002	Malaria transmission risk variations derived from different agricultural practices in an irrigated area of northern Tanzania.	Tanzania	*Anopheles arabiensis*	Outdoors	Pit traps	4	121
Sousa	2001	Dogs as a Favored Host Choice of Anopheles gambiae sensu stricto (Diptera: Culicidae) of Sa˜o Tome´, West Africa	Sao Tome	*Anopheles gambiae*	Indoors	CDC	399	434
Sousa	2001	Dogs as a Favored Host Choice of Anopheles gambiae sensu stricto (Diptera: Culicidae) of Sa˜o Tome´, West Africa	Sao Tome	*Anopheles gambiae*	Indoors	PSC	181	193
Sousa	2001	Dogs as a Favored Host Choice of Anopheles gambiae sensu stricto (Diptera: Culicidae) of Sa˜o Tome´, West Africa	Sao Tome	*Anopheles gambiae*	Outdoors	Indoor manual collection	113	422
Bøgh	2001	Effect of Passive Zooprophylaxis on Malaria Transmission in the Gambia	Gambia	*Anopheles gambiae*	Indoors	PSC	99	177
Bøgh	2001	Effect of Passive Zooprophylaxis on Malaria Transmission in the Gambia	Gambia	*Anopheles gambiae*	Indoors	PSC	96	185
Habtewold	2001	The feeding behaviour and *Plasmodium* infection of *Anopheles* mosquitoes in southern Ethiopia in relation to use of insecticide-treated livestock for malaria control	Ethopia	*Anopheles arabiensis*	Indoors	Indoor manual collection	27	64
Charlwood	2001	The impact of indoor residual spraying with malathion on malaria in refugee camps in eastern Sudan	Sudan	*Anopheles arabiensis*	Indoors	PSC	123	242
Magbity	1997	Effects of community-wide use of lambdacyhalothrin-impregnated bednets on malaria vectors in rural Sierra Leone.	Sierra Leone	*Anopheles gambiae*	Indoors	PSC + CDC	249	253
Magbity	1997	Effects of community-wide use of lambdacyhalothrin-impregnated bednets on malaria vectors in rural Sierra Leone.	Sierra Leone	*Anopheles gambiae*	Indoors	PSC + CDC	397	401
Hadis	1997	Host choice by indoor-resting Anopheles arabiensis in Ethiopia	Ethopia	*Anopheles arabiensis*	Indoors	Indoor manual collection	118	130

Githeko	1994	Origin of blood meals in indoor and outdoor resting malaria vectors in western Kenya	Kenya	*Anopheles arabiensis*	Indoors	PSC	108	232
Githeko	1994	Origin of blood meals in indoor and outdoor resting malaria vectors in western Kenya	Kenya	*Anopheles funestus complex*	Indoors	PSC	86	94
Githeko	1994	Origin of blood meals in indoor and outdoor resting malaria vectors in western Kenya	Kenya	*Anopheles arabiensis*	Outdoors	Indoor manual collection	0	186
Mbogo	1993	BLOODFEEDING BEHAVIOR OF ANOPHELES gambiae S.L. AND ANOPHELES FUNESTUS IN KILIFI DISTRICT, KENYA	Kenya	*Anopheles funestus complex*	Indoors	Indoor manual collection	57	64
Garrett-Jones	1964	The human blood index of malaria vectors in relation to epidemiological assessment	Multiple	*Anopheles funestus complex*	Indoors	Indoor manual collection	179	183
Garrett-Jones	1964	The human blood index of malaria vectors in relation to epidemiological assessment	Multiple	*Anopheles funestus complex*	Outdoors	Indoor manual collection	61	72
Garrett-Jones	1964	The human blood index of malaria vectors in relation to epidemiological assessment	Multiple	*Anopheles funestus complex*	Indoors	Indoor manual collection	1768	2056
Garrett-Jones	1964	The human blood index of malaria vectors in relation to epidemiological assessment	Multiple	*Anopheles funestus complex*	Outdoors	Indoor manual collection	110	243
Garrett-Jones	1964	The human blood index of malaria vectors in relation to epidemiological assessment	Multiple	*Anopheles funestus complex*	Indoors	Indoor manual collection	99	120
Garrett-Jones	1964	The human blood index of malaria vectors in relation to epidemiological assessment	Multiple	*Anopheles funestus complex*	Outdoors	Indoor manual collection	152	423
Garrett-Jones	1964	The human blood index of malaria vectors in relation to epidemiological assessment	Multiple	*Anopheles funestus complex*	Indoors	Indoor manual collection	178	344

Garrett-Jones	1964	The human blood index of malaria vectors in relation to epidemiological assessment	Multiple	*Anopheles funestus complex*	Outdoors	Indoor manual collection	9	193
Garrett-Jones	1964	The human blood index of malaria vectors in relation to epidemiological assessment	Cameroon	*Anopheles funestus complex*	Indoors	Indoor manual collection	53	72
Garrett-Jones	1964	The human blood index of malaria vectors in relation to epidemiological assessment	Zimbabwe	*Anopheles funestus complex*	Outdoors	Indoor manual collection	0	161
Garrett-Jones	1964	The human blood index of malaria vectors in relation to epidemiological assessment	Multiple	*Anopheles gambiae*	Indoors	Indoor manual collection	258	327
Garrett-Jones	1964	The human blood index of malaria vectors in relation to epidemiological assessment	Multiple	*Anopheles gambiae*	Outdoors	Indoor manual collection	3	124
Garrett-Jones	1964	The human blood index of malaria vectors in relation to epidemiological assessment	Multiple	*Anopheles gambiae*	Indoors	Indoor manual collection	1844	2311
Garrett-Jones	1964	The human blood index of malaria vectors in relation to epidemiological assessment	Multiple	*Anopheles gambiae*	Outdoors	Indoor manual collection	172	310
Garrett-Jones	1964	The human blood index of malaria vectors in relation to epidemiological assessment	Multiple	*Anopheles gambiae*	Indoors	Indoor manual collection	418	537
Garrett-Jones	1964	The human blood index of malaria vectors in relation to epidemiological assessment	Multiple	*Anopheles gambiae*	Outdoors	Indoor manual collection	147	524
Garrett-Jones	1964	The human blood index of malaria vectors in relation to epidemiological assessment	Multiple	*Anopheles gambiae*	Indoors	Indoor manual collection	566	696
Garrett-Jones	1964	The human blood index of malaria vectors in relation to epidemiological assessment	Multiple	*Anopheles gambiae*	Outdoors	Indoor manual collection	29	964
Garrett-Jones	1964	The human blood index of malaria vectors in relation to epidemiological assessment	Multiple	*Anopheles gambiae*	Indoors	Indoor manual collection	16	1114
Garrett-Jones	1964	The human blood index of malaria vectors in relation to epidemiological assessment	Multiple	*Anopheles gambiae*	Outdoors	Indoor manual collection	300	940
Garrett-Jones	1964	The human blood index of malaria vectors in relation to epidemiological assessment	Multiple	*Anopheles gambiae*	Indoors	Indoor manual collection	196	265
Garrett-Jones	1964	The human blood index of malaria vectors in relation to epidemiological assessment	Multiple	*Anopheles gambiae*	Outdoors	Indoor manual collection	99	226