

Combined Epidemiologic and Entomologic Survey to Detect Urban Malaria Transmission, Guinea, 2018

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Malaria incidence is generally lower in cities than rural areas. However, reported urban malaria incidence may not accurately reflect the level of ongoing transmission, which has potentially large implications for prevention efforts. To guide mosquito net distribution, we assessed the extent of malaria transmission in Conakry, Guinea, in 2018. We found evidence of active malaria transmission.

Vector control strategies are an important tool for the reduction of malaria burden worldwide. However, these strategies, such as the distribution of mosquito nets (long-lasting insecticidal nets [LLINs]), are effective only in settings of ongoing malaria transmission. Malaria transmission is generally lower in urban areas compared with rural ones (1,2). Moreover, due to population mobility and increased urban access to medical services, malaria cases reported from cities may capture at least some infections acquired in the outlying rural areas, complicating use of incidence data to determine the need for LLINs in urban areas. To guide a recent LLIN distribution campaign, we rapidly assessed malaria transmission in Conakry, Guinea, using a combined epidemiologic and entomologic approach.

The Study

During November 19–December 24, 2018, we conducted community and health facility cross-sectional surveys describing key malaria epidemiologic and entomologic indicators in 10 nonadjacent sites in Conakry, Guinea, by using the methods described by Camara

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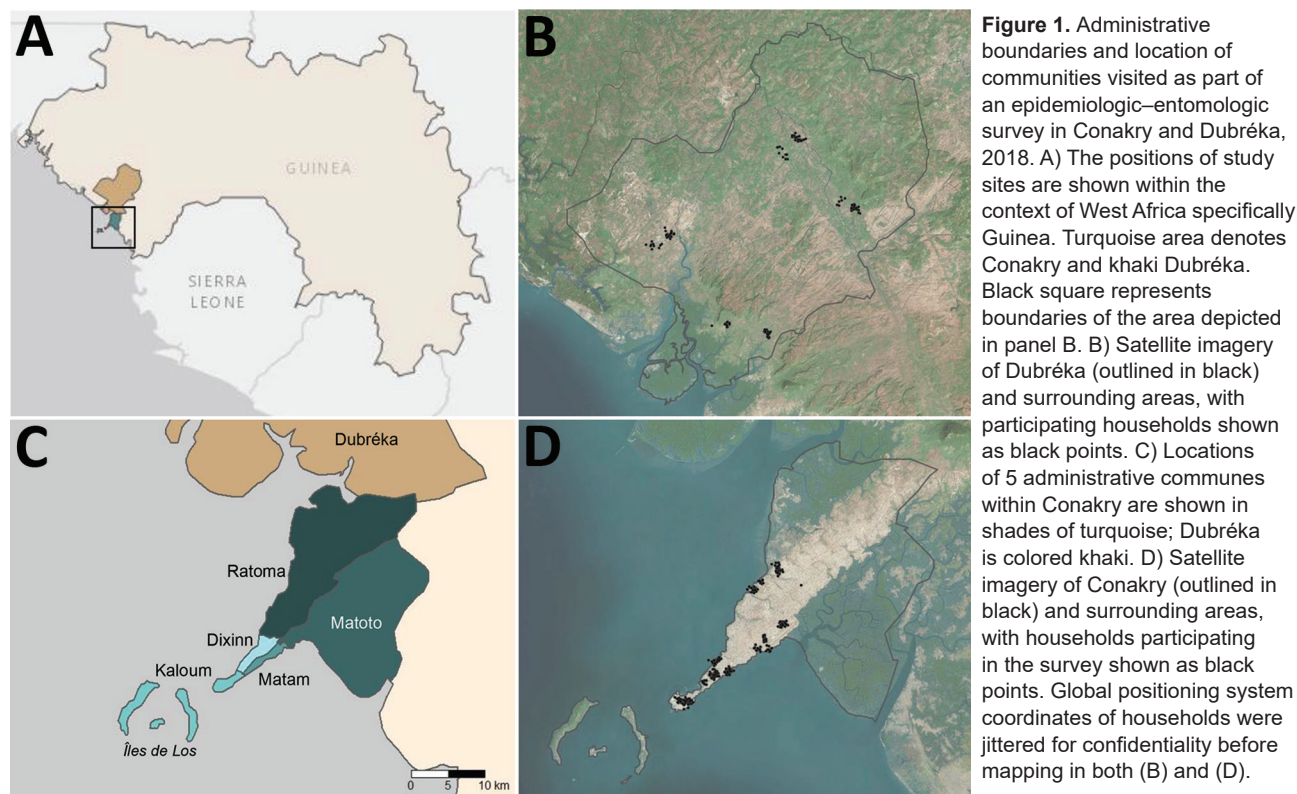
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et al. (3). In addition, a sample of outpatients seeking medical attention were tested for malaria at 25 health-care facilities across Conakry and asked about recent travel outside of the city (Appendix, <https://wwwnc.cdc.gov/EID/article/27/2/19-1701-App1.pdf>).

We conducted a community survey in 300 households throughout Conakry, yielding person-specific data from 2,164 persons and mosquito net access and use data for 1,016 unique sleeping spaces (Figure 1; Appendix Table 1). We performed rapid diagnostic tests (RDTs) to detect *Plasmodium falciparum*-specific antigens for 1,102 (50.9%) of these persons. Surveys conducted in 120 households in 4 villages within the neighboring rural district of Dubréka provided person-specific data for 919 participants and mosquito net access and use data for 486 unique sleeping spaces to serve as a control. We tested 451 (49.1%) control participants for malaria by RDT.

In Conakry, 43.3% of households surveyed claimed to own ≥ 1 mosquito net, compared with 89.2% ($p < 0.001$) of households in Dubréka. Survey participants reported 18.8% (191/1,016) of documented sleeping spaces in Conakry had a mosquito net available at the time of the survey, compared with 63.8% (310/486, $p < 0.001$) in Dubréka. Nets were hanging over 16.7% (170/1,016) of sleeping spaces in Conakry and 59.9% (291/486, $p < 0.001$) of those in Dubréka. However, participant use of nets was similar; 89.0% (170/191) of the available nets in Conakry were in use at the time of the survey, compared with 93.8% (291/310, $p = 0.062$) in Dubréka (Table 1).

Mosquito net access and rates of use were found to be heterogeneous across Conakry. Availability of dedicated mosquito nets ranged from 11.6% (20/173) to 28.6% (63/220) of sleeping spaces when households were grouped by administrative sections (communes). Net use when available ranged from 65.0% (13/20) to 100% (26/26) by commune across Conakry (Table 1).

**Table 1.** Coverage of malaria prevention interventions in and near Conakry, Guinea, 2018*

Characteristic	Conakry, no./total no. (%)					Total	p value†	Dubréka	p value‡
	Kaloum	Dixinn	Matam	Matoto	Ratoma				
LLIN ownership									
Households receiving LLIN in last campaign	50/60 (83.3)	48/60 (80.0)	54/60 (90.0)	52/60 (86.7)	52/60 (86.7)	256/300 (85.3)	0.61	102/120 (85.0)	1
Households with ≥1 LLIN at time of study	14/60 (23.3)	22/60 (36.7)	38/60 (63.3)	24/60 (40.0)	32/60 (53.3)	130/300 (43.3)	<0.001	107/120 (89.2)	<0.001
LLIN access									
Sleeping spaces with LLIN available	20/173 (11.6)	28/169 (16.6)	54/248 (21.8)	26/206 (12.6)	63/220 (28.6)	191/1,016 (18.8)	<0.001	310/486 (63.8)	<0.001
Population sleeping in space with LLIN available	42/366 (11.5)	66/383 (17.2)	108/485 (22.3)	63/445 (14.2)	158/511 (30.9)	437/2,190 (20.0)	<0.001	647/966 (67.0)	<0.001
LLIN use									
Sleeping spaces with LLIN hanging	13/173 (7.5)	26/169 (15.4)	45/248 (18.1)	26/206 (12.6)	60/220 (27.2)	170/1,016 (16.7)	<0.001	291/486 (59.9)	<0.001
Population sleeping in spaces with LLIN hanging	27/366 (7.3)	62/383 (16.2)	89/485 (18.4)	63/445 (14.2)	146/511 (28.6)	387/2,190 (17.3)	<0.001	617/966 (63.9)	<0.001
Spaces with LLIN hanging among those where available	13/20 (65.0)	26/28 (92.9)	45/54 (83.3)	26/26 (100.0)	60/63 (95.2)	170/191 (89.0)	<0.001	291/310 (93.9)	0.062
Proportion sleeping under LLIN in population with access	27/42 (64.3)	62/66 (93.9)	89/108 (82.4)	63/63 (100.0)	146/158 (92.4)	387/437 (88.6)	<0.001	617/647 (95.4)	<0.001
Used LLIN in previous night, <5 y	5/52 (19.6)	19/78 (24.4)	21/99 (21.2)	9/77 (11.7)	24/86 (27.9)	78/392 (19.9)	0.021	137/204 (67.2)	<0.001
Used LLIN in previous night, ≥5 y	14/314 (4.5)	44/298 (14.8)	99/381 (26.0)	40/371 (10.8)	95/408 (23.3)	292/1,772 (16.5)	<0.001	442/716 (61.7)	<0.001
Indoor residual spraying	4/60 (6.7)	1/60 (1.7)	0/60 (0.0)	1/60 (1.7)	0/60 (0.0)	6/300 (2.0)	0.11	1/120 (0.8)	0.68
Any insecticide use	6/60 (10.0)	9/60 (15.0)	10/60 (16.7)	16/60 (26.7)	20/60 (33.3)	61/300 (20.3)	0.012	54/120 (45.0)	<0.001

*Populations determined by summing responses to number of persons sleeping in each space; total denominators do not necessarily match total number of persons reported as living in surveyed households. LLIN, long-lasting insecticidal nets.

†Comparison of results for communes within Conakry.

‡Comparison of results for Conakry and Dubréka.

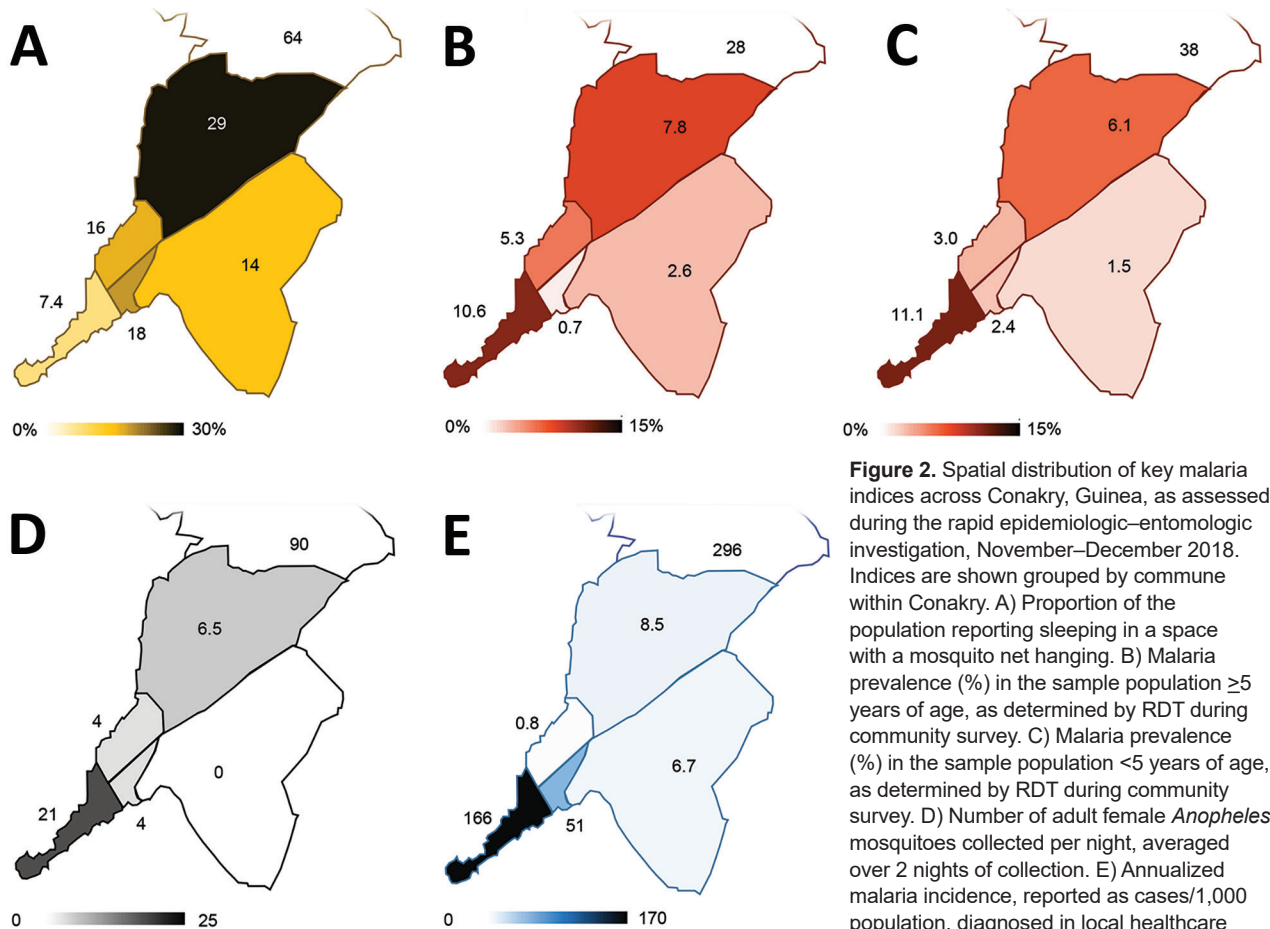


Figure 2. Spatial distribution of key malaria indices across Conakry, Guinea, as assessed during the rapid epidemiologic–entomologic investigation, November–December 2018. Indices are shown grouped by commune within Conakry. A) Proportion of the population reporting sleeping in a space with a mosquito net hanging. B) Malaria prevalence (%) in the sample population ≥ 5 years of age, as determined by RDT during community survey. C) Malaria prevalence (%) in the sample population < 5 years of age, as determined by RDT during community survey. D) Number of adult female *Anopheles* mosquitoes collected per night, averaged over 2 nights of collection. E) Annualized malaria incidence, reported as cases/1,000 population, diagnosed in local healthcare facilities. RDT, rapid diagnostic test.

Malaria prevalence by RDT in both children < 5 years and participants ≥ 5 years was lower in Conakry than in Dubréka (Appendix Table 2). RDT positivity among children < 5 years was 4.3% (14/329) in Conakry and 38.0% (60/158) in Dubréka ($p < 0.001$); in older participants positivity was 5.6% (43/773) in Conakry and 28.0% (82/293) in Dubréka ($p < 0.001$). Within Conakry, the greatest malaria prevalence in both age groups collocated with the lowest rates of mosquito net use and access, although the differences observed between communes in the younger age group failed to reach statistical significance ($p = 0.125$ for age < 5 years, $p < 0.001$ for those ≥ 5 years) (Figure 2). Most participants tested in Conakry (717/1,102, 65.1%) denied having left the city within the last year. Considering only those reporting not having left the city in the past year, we found that 4.0% (29/717) were positive for *P. falciparum* antigen.

Of the 57 participants of all ages who were positive for malaria within Conakry, 75.4% (43/57) reported not leaving the city within the last 4 weeks (Table 2). Thirty-four of these participants (34/57, 59.6%) reported not having left Conakry within the 6 months

before interview, and 50.9% (29/57) did not leave the city within the year before interview. Nearly one fifth of Conakry residents were positive for malaria reported never having left the city (17.5%, 10/57).

A random intercept, mixed effects regression model to identify risk factors for *P. falciparum* antigenemia demonstrated statistically significant associations with self-reported travel outside the city ($p < 0.23$). Odds ratios were 2.2–7.3 and were higher for more recent travel (Appendix Table 3).

We collected recent travel history data from 4,678 persons seeking medical attention whose diagnostic workup included malaria testing by microscopy or RDT. Of these persons, 8.0% (376/4,678) reported travel outside Conakry within the 4 weeks before being tested. Malaria antigen was detected in 57.7% (217/376) of those reporting having left the city in the last 4 weeks, compared with 26.5% (1,139/4,302) of those who remained in Conakry in the same period (Appendix Table 4). The overall relative risk for malaria positivity associated with travel outside of Conakry within the last 4 weeks was 2.2 (95% CI 2.0–2.4). The corresponding population

Table 2. Characteristics of persons testing positive for malaria infection, Guinea, 2018*

Characteristic, n/N (%)	Conakry						p value†	Dubr�ka	p value‡
	Kaloum	Dixinn	Matam	Matoto	Ratoma	Total			
LLIN use previous night, <5 y	0/5 (0.0)	0/2 (0.0)	0/2 (0.0)	1/1 (100)	0/4 (0.0)	1/14 (7.1)	0.07	41/60 (68.3)	<0.001
LLIN use previous night, ≥5 y	0/17 (0.0)	0/8 (0.0)	0/1 (0.0)	1/4 (25.0)	4/13 (30.8)	5/43 (11.6)	0.042	46/82 (56.1)	<0.001
Fever ≤2 wk of RDT	15/22 (68.2)	3/10 (30.0)	2/3 (66.7)	5/5 (100)	9/17 (52.9)	34/57 (59.6)	0.092	75/135 (55.6)	0.64
History of travel outside Conakry, ≤4 wks	4/22 (18.2)	5/10 (50.0)	0/3 (0.0)	1/5 (20.0)	4/17 (23.5)	14/57 (24.6)	0.37	NA	
History of travel outside Conakry, ≤6 mo	5/22 (22.7)	7/10 (70.0)	0/3 (0.0)	2/5 (40.0)	9/17 (52.9)	23/57 (40.4)	0.04	NA	
No travel outside Conakry within last year	17/22 (77.3)	2/10 (20.0)	1/3 (33.3)	2/5 (40.0)	7/17 (41.2)	29/57 (50.9)	0.016	NA	

*In a joint epidemiologic–entomologic investigation of urban malaria transmission in Guinea, participants were tested by using rapid diagnostic test during community screening. LLIN, long-lasting insecticidal net; NA, not applicable; RDT, rapid diagnostic test.

†Comparison of results for communes within Conakry.

‡Comparison of results for Conakry and Dubr ka.

attributable risk of travel outside the city was calculated as 8.7%. Although rates of malaria positivity and recent travel history both showed large variation, associated relative risks for individual communes were 1.56–3.57 and population-attributable fractions of risk were 4.6%–17.0% across different communes in Conakry.

Collection of adult mosquitoes as part of the study demonstrated the presence of female *Anopheles gambiae* sensu lato mosquitoes in 4/5 communes in Conakry. We captured an average of 21 adult female *A. gambiae* sl. mosquitoes nightly at the urban site yielding the greatest number of *Anopheles* mosquitoes in Conakry (Figure 2; Appendix Figure 1). In contrast, adult mosquito collection from 2 rural sites in Dubr ka yielded an average of 90 female *Anopheles gambiae* sensu lato mosquitoes captured per night. However, the nightly yield was highly heterogeneous by site, with 1 of the 2 sites accounting for 99.4% (358/360) of the female *Anopheles* mosquitoes captured (Appendix Figure 2).

Conclusions

We found multiple corroborating lines of evidence that strongly indicate malaria is actively transmitted in Conakry. The presence of *Anopheles* vectors, current or recent malaria infections in the absence of any plausible travel-related exposures, and the spatial distribution of infection mirroring that of risk factors for local acquisition of disease all suggest ongoing malaria transmission. Rural control sites had greater observed densities of competent vectors and higher prevalence of malaria. In addition, travel outside of the city was found to be a risk for malaria infection for persons living in Conakry. However, we found that the risk associated with travel was a minor contributor to the overall malaria burden in Conakry, indicating that residents appear to be at risk, albeit a decreased one, of acquiring malaria within the confines of the city.

Given the likely ongoing malaria transmission, coupled with the high rate of net use when available, LLIN distribution is a suitable malaria control strategy in Conakry. The observed heterogeneity of malaria transmission across the city raises the potential for more targeted distribution of prevention commodities. Additional studies are needed to confirm and further refine this finding.

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About the Author

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Appendix

Additional Contextual Information

Conakry is Guinea's largest city with an estimated population of 1.8 million in 2016 (1). The city has 5 administrative communes (Figure 1), which vary in size and population (ranging from 70,000–700,000) (1).

Although national household surveys demonstrated the overall prevalence of malaria among children <5 years of age to be 44% in 2012 and 30% in 2016, prevalence in Conakry was 3% in 2012 and 2% in 2016 (2,3). Surveillance of incident malaria cases in Conakry reveals a similar overall pattern; estimated annual incidence for all ages was 18 confirmed cases/1,000 inhabitants. In contrast, the more rural area directly neighboring the city had a recently documented prevalence of 10% (3) and incidence of 169 cases/1,000 residents (4). All reported cases of malaria from Guinea to the World Health Organization have been due to *Plasmodium falciparum* infection for several years (5).

The National Malaria Control Program (NMCP) in Guinea distributes LLINs nationally on a triennial schedule. Previous distribution campaigns were held in 2013 and 2016. Prior to the LLIN distribution campaign in 2019, we sought to rapidly assess malaria transmission in Conakry to ensure nets would be effective. Definitive proof of malaria transmission often relies on demonstration of *Plasmodium*-infected mosquitoes (6). However, definitively ascertaining transmission using purely entomological means requires large samples of *Anopheles* mosquitoes captured in the city and often over long periods (7–12). Similarly, most previously published epidemiological methods to gauge urban malaria transmission were also done over longer periods (12–20). A series of rapid investigations of urban malaria epidemiology in a select number of cities have been published previously, but these do not address the potential discrepancy between prevalence and active transmission (21–27). Using a combined approach, we sought to provide actionable information on urban malaria transmission in a timely fashion to inform a rapidly approach LLIN distribution campaign.

Methods

Study Site, Population, and Sampling Approach

All 5 communes of Conakry were entirely included in the consideration for study site selection with the exception of 3 islands off the coast, which are technically part of the city but rural in nature. Routine malaria surveillance data from July–September 2018 were reviewed to identify the areas within each commune reporting the highest malaria incidences. Using these data, 2 geographically separate facility catchment areas were chosen within each of the city's 5 communes (10 urban areas overall) on the basis of elevated malaria incidence as well as input from local partners regarding feasibility and logistic concerns. Each catchment area selected served to provide the sampling units for all phases of the study involving community sampling (households, health facilities, and environmental evaluation for vectors). A similar procedure was conducted for the selection of 4 rural control sites within the rural prefecture of Dubréka just outside of Conakry.

At all chosen healthcare facilities, potential neighborhoods for household surveys were identified by soliciting input from healthcare workers and clinic officials to determine the specific locations contributing the most cases of malaria within the catchment area. The choice of final locations for study were the results of open discussions held between investigators and clinical staff, taking into account malarial disease burden, individual neighborhood accessibility, and overall feasibility.

Household Surveys

Within each study site, investigators randomly selected 30 households using a modified sampling method based on the WHO expanded program on immunization methodology (28). Surveys were administered at every third household. At each household, investigators used standardized questionnaires to collect information from the self-identifying head of household. Another adult member of the household was interviewed in lieu of the head of household if needed. All data, including number of household mosquito nets, number of nets hanging, and number of nets in good repair, were collected by participant response rather than surveyor observation. Surveys were designed to assess risk factors for local acquisition of disease as well as travel patterns of Conakry residents. Surveys were conducted and data were collected using electronic tablets loaded with SurveyCTO software version 2.50 (Dobility, <https://www.dobility.com>).

A maximum of 4 members per household were tested for the presence of *Plasmodium falciparum*-specific histidine-rich protein 2 (HRP2) antigen in the blood using rapid diagnostic tests (RDTs) (SD Bioline Malaria Ag P.f.; Abbott Laboratories, <https://www.abbott.com>). Children <5 years

were prioritized for testing in order to participants with a limited travel history outside the city. If fewer than 4 children < 5 years were present in the household, testing was offered to other household members, first by offering testing to pregnant women, followed by randomization of older children and non-pregnant adults. If more than 4 children <5 years of age were present, 4 of them were chosen at random for screening. All individuals found to be positive for *P. falciparum* by RDT were given artemisinin-based combination therapy and instructions for use, in accordance with national guidelines.

Healthcare Facility Visits

Registers and routine surveillance reporting forms from each selected healthcare facility were reviewed. Investigators reviewed clinical registers from July–September 2018 to enumerate all-cause consultations, cases of febrile illness (defined as documented subjective fever and or temperature $\geq 38.5^{\circ}$ C), cases of confirmed malaria, cases of malaria meeting WHO criteria of severity (Appendix Table 5) (29), and malaria-attributable deaths (death in the setting of documented severe malaria in the absence of alternative identified cause). These figures were compared to those reported to the NMCP as part of the monthly national malaria surveillance program.

Travel-Related Risk in Outpatients

Data regarding potential travel-related exposures were collected from persons seeking healthcare throughout Conakry from December 8–27, 2018. All patients visiting participating outpatient facilities for medical attention whose clinical workup included malaria testing were asked to disclose any travel outside the city within the 4 weeks before illness onset. Each facility collected data for 2 weeks using standardized paper forms. Clinical testing was performed in each facility according to its own diagnostic protocols and included a mix of microscopy and RDT. Data were subsequently transcribed to Microsoft Excel 2016 (Microsoft Corporation, <https://www.microsoft.com>) data files for analysis.

Potential Larval Habitat Enumeration

Mosquito larval surveys were conducted in Conakry by performing exhaustive searches for all accessible pools of standing water within delineated areas of roughly 50,000–90,000 m². Search areas were chosen by soliciting healthcare worker and resident opinions on the area within each targeted neighborhood most heavily infested with mosquitoes, a method previously documented to be effective by Mwangungulu et al. (30) One survey field was defined for each commune of the city, resulting in a total of 5 urban sites for larval characterization (Appendix Figure 3).

Larval habitat surveys in Dubréka were performed using defined straight line transects to visualize all sources of standing water along the long axis of selected villages rather than within predefined areas. Subsequent, shorter transects were performed in each village at right angles to the

initial path. Two of the 4 villages from Dubréka included in the overall study were chosen for potential larval habitat survey and characterization (Appendix Figure 4).

In all study locations, all collections of standing water were examined for the presence of mosquito larvae. Any mosquito larvae found were classified to the genus level by entomologists. Larvae were not quantified in either relative or absolute terms. Data were collected and stored on electronic tablets loaded with SurveyCTO software.

Adult Mosquito Collection

Adult mosquitoes were captured by human landing catches within each search area selected for larval habitat characterization. Mosquito collections took place continuously from 6:00 PM–7 AM on 2 consecutive nights at each study location. Collections were performed by 2 volunteers working simultaneously, 1 collecting mosquitoes outdoors and the other collecting mosquitoes inside the household of a neighborhood/village resident. Collectors were provided antimalarial prophylaxis free of charge. Adult mosquito collection sites were selected by entomologists to maximize potential nightly yield.

Adult mosquitoes were segregated by location of collection (indoors vs. outdoors) and hour of collection. All mosquitoes were subsequently sexed and morphologically identified to genus. *Anopheles* mosquitoes were morphologically identified to the species/group level.

Data Analysis

Data collected from the household surveys, healthcare facility visits, and entomological studies were subsequently analyzed using R version 3.5.0 (R Foundation for Statistical Computing, www.r-project.org). Data from each commune of Conakry were both statistically compared to one another and aggregated to compare Conakry as a whole against the rural control sites. Fischer's exact test was used for comparison of categorical variables, using an α of 0.05 modified using Bonferroni's correction for multiple comparisons when needed. Factors found to be statistically significant under the assumption of independence (i.e., no clustering) were used to build single variable mixed effects, random intercept models to assess the vigor of statistical significance while accounting for the spatial clustering of data. Household survey data were additionally used to model *P. falciparum* antigenemia using generalized linear mixed effect models using the lme4 package in R (<https://github.com/lme4/lme4>). Predictors included in the multivariable, random intercept model were respondent age, city commune of residence, travel history, pregnancy status, and self-reported insecticide-treated net use.

Data collected from outpatient visits were used to calculate relative risks, 95% CI, and population-attributable fractions for potential travel-related exposures using Excel. Reported population attributable fractions were calculated using the formula $(I_P - I_U)/I_P$, where I_P = total incidence of malaria at each health facility and I_U = incidence of malaria among non-travelers at each health facility.

Maps for visualization of epidemiological data were generated using tmap package in R (<https://github.com/mtennekes/tmap>) with shapefiles acquired from GADM (https://gadm.org/download_country_v3.html) and the Humanitarian Data Exchange (<https://data.humdata.org/dataset/guinea-geodatabase>).

Ethical Considerations

Verbal informed consent was obtained from all participants of this study. Written informed consent form was obtained for each of those participating in the household survey and malaria prevalence screen by RDT. The signature of a parent or guardian was obtained for all children <18 years of age tested by RDT. The protocol for this study was reviewed and approved as a non-research activity by the Center for Global Health's Office of the Director at the Centers for Disease Control and Prevention (#2017-347a), as well as the Guinea Ministry of Health.

Additional Results

Febrile Illness and Health-Care Seeking Behavior

Rates of subjective fever during the 2 weeks prior to interview were slightly lower in Conakry (18.6%, 398/2,138) than in Dubréka (24.4%, 109/813, $p < 0.001$) (Appendix Figure 5). Reported fever within Conakry also varied by commune, from 15.2% (74/486) to 24.6% (89/362), although these differences did not attain statistical significance when accounting for multiple comparisons using Bonferroni corrections ($p = 0.0185$).

Healthcare-seeking behavior for febrile illnesses was largely similar across all study sites (Appendix Figure 6). Use of private medical facilities was more common in Conakry (16.7%, 67/402) than in Dubréka (3.0%, 6/198; $p < 0.001$). However, there were no other significant differences in utilization of healthcare facilities by type, including public facilities. Of those experiencing febrile illness, 29.4% (118/402) sought care at a public health facility in Conakry compared to 32.3% (64/198) in Dubréka ($p = 0.51$). The variations in healthcare-seeking behavior observed across communes of Conakry did not attain statistical significance after accounting for multiple comparisons.

Health Facility Record Review

The facilities in Conakry exhibited variable utilization rates during this time, as evidenced by annualized all-cause incidences ranging from 13–445 consultations/1,000 individuals (Figure 2; Appendix Table 6). One facility visited in the commune of Dixinn serves as a national referral center with a reported catchment population of 12 million people. Although available to the entire population under extraordinary medical circumstances, this reported catchment artificially drives down reported incidences, and as such, the results from this institution are not included in this discussion. Malaria accounted for 15%–71% of all medical consultations among the facilities visited in Conakry.

Compared with the results seen in Conakry, the reported incidences of malaria, all-cause consultation rates, and the proportion of visits attributable to malaria were all greater in the facilities visited in Dubréka, on average. Within Conakry, only the facilities in Kaloum reported figures (167 and 179 cases per 1,000 residents) rivaling those seen routinely in Dubréka (range 167–578 cases/1,000) (Appendix Table 6; Appendix Figure 7).

The facility-reported data from both Dubréka and Conakry were found to be largely accurate when compared with registry records. All clinical sites in the study produced both surveillance reporting forms and clinical registers for comparison for all months requested. Of the 14 sites visited, 12 had reported malaria incidence data to within 10% of the true values listed in the clinical registers (Appendix Table 6, Appendix Figure 8). Notable discrepancies between the reported and registered sources of data were identified at 2 clinical sites. At both locations, both the reported number of consults and the reported number of malaria cases were incorrectly elevated during the period examined.

Potential Larval Habitat Enumeration

Potential mosquito larval habitats were sampled in 5 designated areas across Conakry and 2 linear village transects in Dubréka. A total of 187 potential larval habitats were identified within Conakry, and 28 were identified in Dubréka (Appendix Table 7; Appendix Figure 4). The types and proportions of larvae found in Conakry and Dubréka did not statistically differ from one another. No *Anopheles* larvae were found in Conakry; 1 *Anopheles* sp. larval habitat was identified in Dubréka. The most frequently identified mosquito larvae in both Conakry and Dubréka were *Culex* sp. (Appendix Table 7).

Discussion

Heterogeneity of Transmission

Using the data we collected, we can calculate a crude approximation of the relative effectiveness of nets as a disease preventative in the locations studied. The ratio of nets needed to provide universal coverage to the number of locally acquired incident cases would be much higher in Conakry (11:1) as compared to Dubréka (1.2:1), where incidence is several-folds higher and risk of acquiring malaria is greater. Similarly, within Conakry itself, we noted considerable heterogeneity of the risk of locally acquired malaria. Using the PAR to adjust for the risk of malaria associated with travel outside the city, the incidence of locally acquired, clinically diagnosed malaria is 1.79–3.08 times higher in Kaloum than that in the other 4 communes of Conakry. This heterogeneity in risk of local malaria infection could have profound implications for the distribution of mosquito nets in the future. For instance, recalculating the nets required for universal coverage of the population of Kaloum and the number of estimated locally acquired malaria cases gives a ratio of 3.1:1. Thus, these data can be used to not only ascertain the need for net distribution in Conakry, but also to prioritize portions of the city over others in the event the campaign is unable to provide universal coverage. Of note, these calculations rely on a number of assumptions that our rapid study cannot ensure, thereby reducing their overall precision and accuracy.

Limitations

While our study quickly gathered actionable information crucial to the NMCP for use during its net distribution campaign, it does have important limitations. In order to achieve results in a timely fashion, some generalizability had to be sacrificed. The findings presented here summarize a brief snapshot in time, and as such, cannot be used to make broad generalizations of malaria transmission throughout the year. Although we were able to demonstrate the likely presence of ongoing autochthonous malaria transmission in Conakry, estimations of the relative contribution of local transmission to urban disease burden are subject to a seasonal variability that we are unable to document here.

In addition to the temporal restrictions on the generalizability of our findings, the study populations in both Conakry and Dubréka are not representative of the underlying populations overall because they were purposefully selected. Not only were those in the geographic areas of greatest risk consciously selected, but children <5 years were overrepresented in the household testing. Odds ratios and comparisons as calculated are thus not reflective of Conakry and Dubréka overall but are rather comparisons of the subpopulations of each in the areas with the greatest disease burden. We purposefully biased our sample to increase our ability to detect the presence of low levels of ongoing

local malaria transmission at the expense of some degree of quantitative accuracy of the underlying population as a whole. More robust quantification of the risk of contracting malaria in Conakry requires more extensive sampling over a longer period.

Despite these limitations, our approach allowed us to describe the heterogeneity in urban disease burden and to provide an estimation of the risk of local disease acquisition in a relatively short period and within a relatively modest budget of \$15,000. Moreover, in contrast to earlier studies, our study was conducted in the context of increasingly available routine data. Routine data were used to select study sites and were found to be generally reliable over the course of the study, thus providing evidence that routine data can be used for further monitoring of malaria risk in Conakry. The results of our study, while not broadly generalizable, yielded practical, actionable information in a timely fashion to directly influence use of disease prevention resources.

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Appendix Table 1. Characteristics of households and household members visited during an entomological–epidemiologic survey of urban transmission in Conakry, Guinea, 2018*

Characteristic	Conakry						Total	Dubreka
	Kaloum	Dixinn	Matam	Matoto	Ratoma			
No. households	60	60	60	60	60	300	120	
No. people	366	376	480	448	494	2164	919	
Average occupancy	6.1	6.3	8.0	7.5	8.3	7.2	7.7	
Average age, y	24.1	22.3	22.2	20.8	19.4	21.6	20.3	
% <5 y of age	14.2	20.7	20.6	17.2	17.4	18.1	22.2	
% Pregnant women	2.7	1.9	1.9	0.9	1.8	1.8	3.0	
No. persons tested by RDT	205	217	229	219	232	1,102	451	
No. sleeping spaces documented	173	169	248	206	220	1,016	486	
No. persons/sleeping space	2.1	2.2	2.0	2.2	2.3	2.1	1.9	

*Dubreka population served as rural control. RDT, rapid diagnostic testing.

Appendix Table 2. Characteristics of persons tested for *Plasmodium falciparum* malaria infection, Guinea, 2018*

Characteristic, n/N (%)	Conakry						p value†	Dubreka	p value‡
	Kaloum	Dixinn	Matam	Matoto	Ratoma	Total			
No. persons tested by RDT	205	217	229	219	232	1102		451	
Persons <5 y tested, %	22.0	30.6	36.2	31.1	28.4	29.9	0.031	35.0	0.047
Positivity by RDT, <5 y	5/45 (11.1)	2/67 (3.0)	2/83 (2.4)	1/68 (1.5)	4/66 (6.1)	14/329 (4.3)	0.13	60/158 (38.0)	<0.001
Positivity by RDT, ≥ 5 y	17/160 (10.6)	8/150 (5.3)	1/146 (0.7)	4/151 (2.6)	13/166 (7.8)	43/773 (5.6)	<0.001	82/293 (28.0)	<0.001
Positivity by RDT, pregnant women	3/9 (33.3)	0/6 (0.0)	0/9 (0.0)	0/4 (0.0)	3/8 (37.5)	6/36 (16.7)	0.079	2/24 (8.3)	0.46
No history of travel outside Conakry for ≥1 y	154/205 (75.1)	127/217 (58.5)	143/229 (62.4)	148/219 (67.6)	145/232 (62.5)	717/1,102 (65.1)	NA	NA	NA
RDT+	17/154 (11.0)	2/127 (1.6)	1/143 (0.7)	2/148 (1.4)	7/145 (4.8)	29/717 (4.0)	<0.001	NA	NA

*In a joint epidemiologic–entomologic investigation of urban malaria transmission in Guinea, participants were tested by rapid diagnostic test (RDT) during community screening. NA, not applicable.

†Comparison of results for communes within Conakry.

‡Comparison of results for Conakry and Dubreka

Appendix Table 3. Factors associated with testing positive by RDT during entomological-epidemiologic assessment of urban transmission in Conakry, 2018*

Factor	Coefficients	Odds ratio	95% CI	p value	RDT positivity within group, n/N (%)
Fixed effects					
District					
Matam		Reference			3/229 (1.3)
Dixinn		3.329	(0.78,18.18)	0.12	10/217 (4.6)
Matoto		2.217	(0.43,13.28)	0.34	5/219 (2.3)
Ratoma		6.795	(1.76,36.15)	0.0099	17/232 (7.3)
Kaloum		13.968	(3.63,78.83)	0.00052	22/205 (10.7)
Age, y					
0–4		Reference			14/329 (4.3)
5–14		0.987	(0.41,2.35)	0.98	16/278 (5.8)
15–29		0.859	(0.33,2.21)	0.75	21/254 (8.3)
≥30		0.185	(0.05,0.57)	0.0054	6/241 (2.5)
Last time outside Conakry					
Never left Conakry		Reference			10/404 (2.5)
Within last 4 wk		7.269	(2.48,23.17)	0.00041	14/145 (9.7)
4 wk–6 mo		4.990	(1.53,16.19)	0.0068	9/110 (8.2)
6 mo–1 y		2.232	(0.56,8.09)	0.23	5/128 (3.9)
>1 y		2.809	(1.07,7.84)	0.039	19/313 (6.1)
Other: pregnancy					
Denied pregnancy		Reference			51/1,065 (4.8)
Pregnant		3.852	(0.95,15.79)	0.056	6/36 (16.7)
Other: used LLIN					
Did not sleep under net last night		Reference			51/902 (5.7)
Slept under net last night		0.561	(0.17,1.58)	0.30	6/200 (3.0)
Random effects	Intercept grouped by household†				
			(0.54,2.48)		

*LLIN, long-lasting insecticidal net; RDT, rapid diagnostic test.

†SD = 1.411.

Appendix Table 4. Malaria test results and self-disclosed travel history <4 wk before seeking medical attention for suspected malaria, Conakry, December 2018

Characteristic	Conakry						p value
	Kaloum	Dixinn	Matam	Matoto	Ratoma	Total	
No. patients tested	181*	222	729	1,107	2,440	4,678	
No. blood smears	0	0	12	1†	18	31†	
No. RDTs	181*	222	717	1,107	2,422	4,648	
Confirmed positive cases, n/N (%)	116/180 (64.4)	53/222 (23.9)	149/729 (20.4)	273/1,107 (24.7)	765/2,440 (31.4)	1,356/4,678 (29.0)	<2.2 × 10 ⁻¹⁶
Positive travel history in patients testing positive, n/N (%)	55/116 (47.4)	7/53 (13.2)	31/149 (20.8)	55/273 (20.1)	69/765 (9.0)	217/1,356 (16.0)	<2.2 × 10 ⁻¹⁶
Positive overall travel history, n/N (%)	66/180 (36.7)	8/222 (3.6)	50/729 (6.9)	138/1,107 (12.5)	114/2,440 (4.7)	376/4,678 (8.0)	<2.2 × 10 ⁻¹⁶
Positive RDT result in patients who traveled, n/N (%)	55/66 (83.3)	7/8 (87.5)	31/50 (62.0)	55/138 (39.9)	69/114 (60.5)	217/376 (57.7)	
Relative risk of traveling outside Conakry	1.56	4.07	3.57	1.77	2.02	2.18	
Population-attributable fraction of risk associated with recent travel, %	17.0	10.0	15.0	8.8	4.6	8.7	

*One record was excluded from travel analysis due to contradicting, duplicate entry indicated a simultaneous positive and negative travel history. RDT, rapid diagnostic test.

†One patient received both a blood smear for microscopy and RDT.

Appendix Table 5. Severe malaria criteria in addition to a laboratory confirmation, as defined by the World Health Organization, 2015*

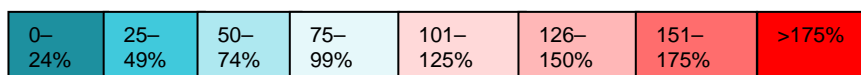
Symptom	Description
Impaired consciousness	Glasgow score <11 in adults or a Blantyre coma score <3 in children
Prostration	Generalized weakness such that patient is unable to sit, stand, or walk without assistance
Multiple convulsions/seizures	>2 episodes within 24 h
Acidosis	A base deficit >8 mEq/L, or plasma bicarbonate level <15 mmol/L, or venous plasma lactate ≥5 mmol/L. Severe acidosis manifests clinically as respiratory distress
Hypoglycemia	Blood or plasma glucose <2.2 mmol/L (<40mg/dL)
Anemia	Hemoglobin concentration ≤5 g/dL or hematocrit ≤15% in children <12 years of age with <i>P. falciparum</i> parasite count >10 000/uL; hemoglobin concentration <7 g/dL or hematocrit <20% in adults WITH <i>P. falciparum</i> parasite count >10,000/uL
Renal Impairment	Plasma or serum creatinine concentration >265 μmol/L (>3 mg/dL) or blood urea concentration >20 mmol/L
Jaundice	Plasma or serum bilirubin concentration >50 μmol/L (>3 mg/dL) with <i>P. falciparum</i> parasite count >100,000/μL
Pulmonary edema	Radiographically confirmed OR O2 saturation <92% on room air with respiratory rate >30/min
Significant bleeding	Recurrent or prolonged bleeding from the nose, gums, or venipuncture sites; hematemesis or melena
Shock	Compensated shock is defined as capillary refill ≥3 seconds or temperature gradient on leg (mid to proximal limb), but no hypotension. Decompensated shock is defined as systolic blood pressure <70 mm Hg in children or <80 mm Hg in adults, with evidence of impaired perfusion (cool peripheries or prolonged capillary refill)
Hyperparasitemia	<i>P. falciparum</i> parasitemia >10%

*Definition taken from the 2015 World Health Organization Guidelines for the Treatment of Malaria, 3rd edition: a laboratory-confirmed case of malaria (i.e., confirmed by light microscopy visualization of parasites in patient blood smear or immunologic detection of parasite antigen with RDT) with any one of the symptoms listed.

Appendix Table 6. Healthcare facility malaria indicators as reported by routine surveillance (left) compared with figures verified in clinical registers during rapid epidemiologic–entomologic investigation (right), July–September 2018

Location	Reported by routine surveillance			Reported cases as % of confirmed cases in registers*		
	All-cause incidence	Malaria incidence	% Malaria	All-cause	Confirmed malaria	% Malaria
Conakry						
Kaloum A	202	167	71	100	99	100
Kaloum B	358	179	50	101	101	100
Dixinn A	445	79	18	101	101	100
Dixinn B	1	0.2	24	133	176	130
Matam A	315	50	16	103	101	98
Matam B	338	51	15	98	102	104
Matoto A	19	5	25	102	90	90
Matoto B	82	19	23	100	99	99
Ratoma A	13	4	30	115	176	150
Ratoma B	163	51	31	100	100	99
Dubrėka						
Dubrėka A	752	578	77	99	100	99
Dubrėka B	601	448	75	100	100	99
Dubrėka C	369	212	57	100	100	100
Dubrėka D	304	167	55	99	101	102

*Shading indicates a range of underreporting (deep turquoise) to overreporting (deep red) of data.



Underreporting

Overreporting

Appendix Table 7. Key results of mosquito larval habitat searches conducted during rapid epidemiologic–entomologic investigation of urban malaria transmission, Guinea, 2018*

Result	Conakry						p-value†	Dubrėka	p-value‡
	Kaloum	Dixinn	Matam	Matoto	Ratoma	Total			
Total potential larval habitats sampled	35	34	28	40	50	187		28	
Area sampled, m ² §	89,983	49,287	83,343	72,912	94,737	390,262		NA	
1/Sampling density, m ⁻²	2,571	1,450	2,977	1,823	1,895	2,087		NA	
No. without mosquito larvae, n/N (%)	28/35 (80.0)	19/34 (55.9)	15/28 (53.6)	33/40 (82.5)	35/50 (70.0)	130/187 (69.5)	0.023	21/28¶ (75.0)	0.71
No. with <i>Anopheles</i> larvae n/N (%)	0/35 (0.0)	0/34 (0.0)	0/28 (0.0)	0/40 (0.0)	0/50 (0.0)	0/187 (0.0)		1/28¶ (3.6)	0.27
No. with <i>Culex</i> larvae n/N (%)	7/35 (20.0)	13/34 (38.2)	9/28 (32.1)	7/40 (17.5)	12/50 (24.0)	48/187 (25.7)	0.24	5/28¶ (17.9)	0.51
1/ <i>Culex</i> larval site density (m ⁻²)	12,855	3,791	9,260	10,416	7,895	8,130		NA	
No. with <i>Aedes</i> larvae n/N (%)	0/35 (0.0)	2/34 (5.9)	4/28 (14.3)	0/40 (0.0)	3/50 (6.0)	9/187 (4.8)	0.049	3/28¶ (10.7)	0.41
1/ <i>Aedes</i> larval site density (m ⁻²)	0	24,644	20,834	0	31,579	43,362		NA	

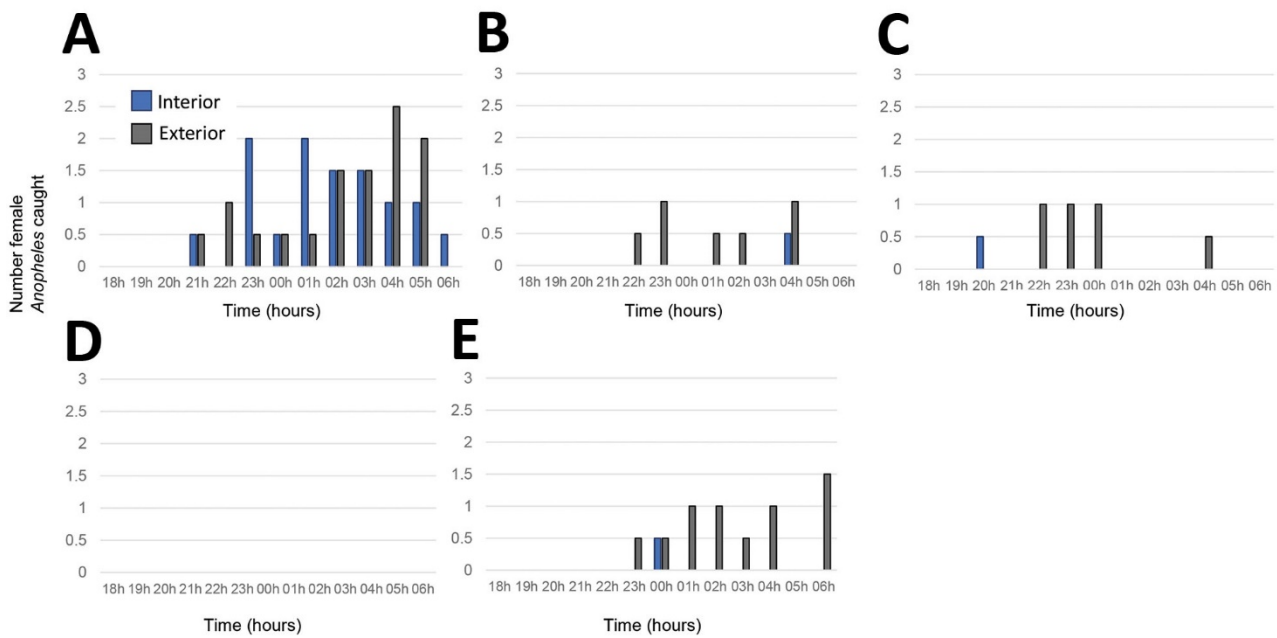
*NA, not applicable.

†Comparison of results for communes within Conakry.

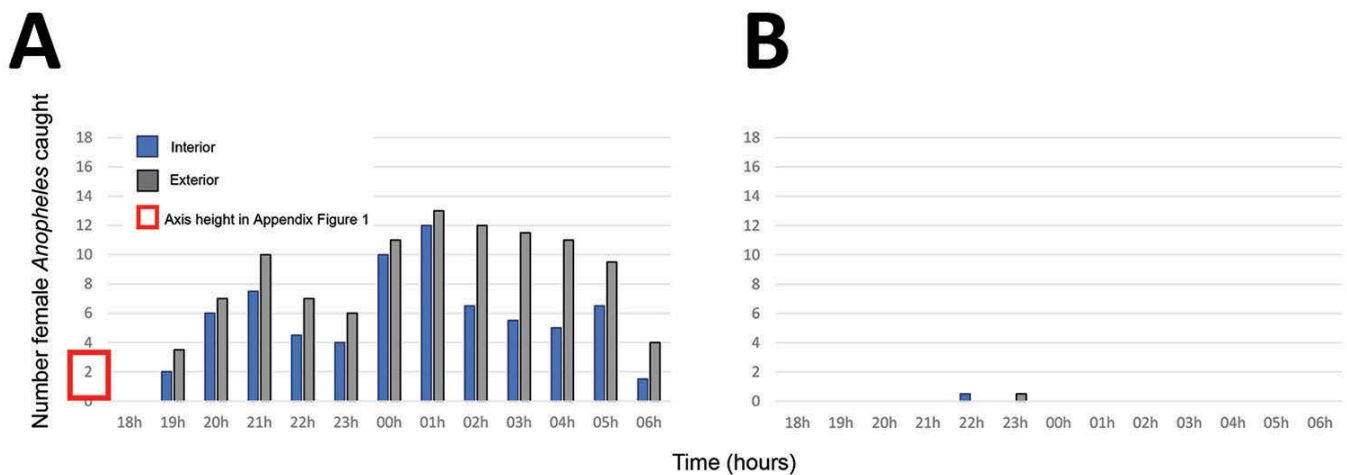
‡Comparison of results for Conakry and Dubrėka.

§Area sampled estimated using Google Maps (see Appendix figure 1). Larval habitats in Dubrėka sampled via transect, precluding calculation of density.

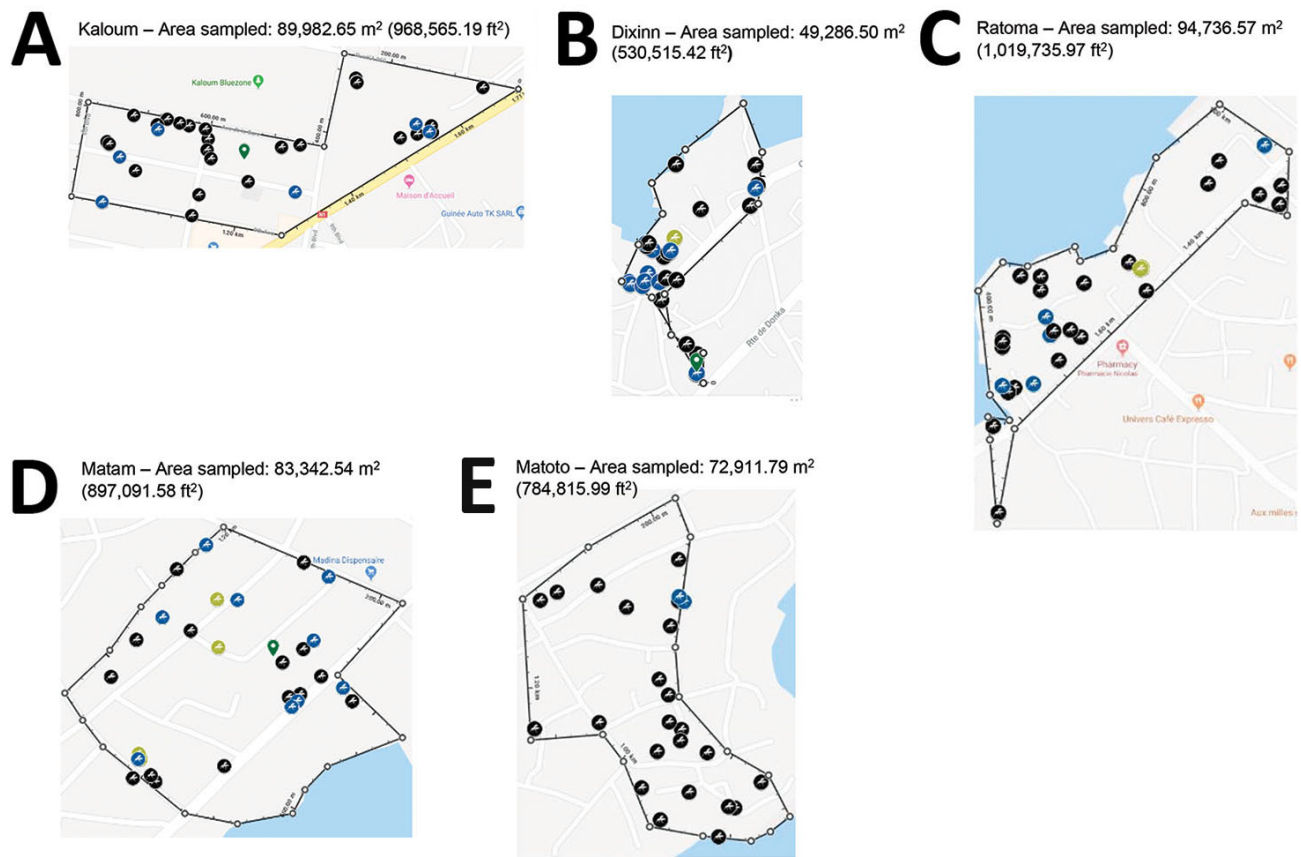
¶Numerators do not add to denominator due to larval habitats containing multiple genera.



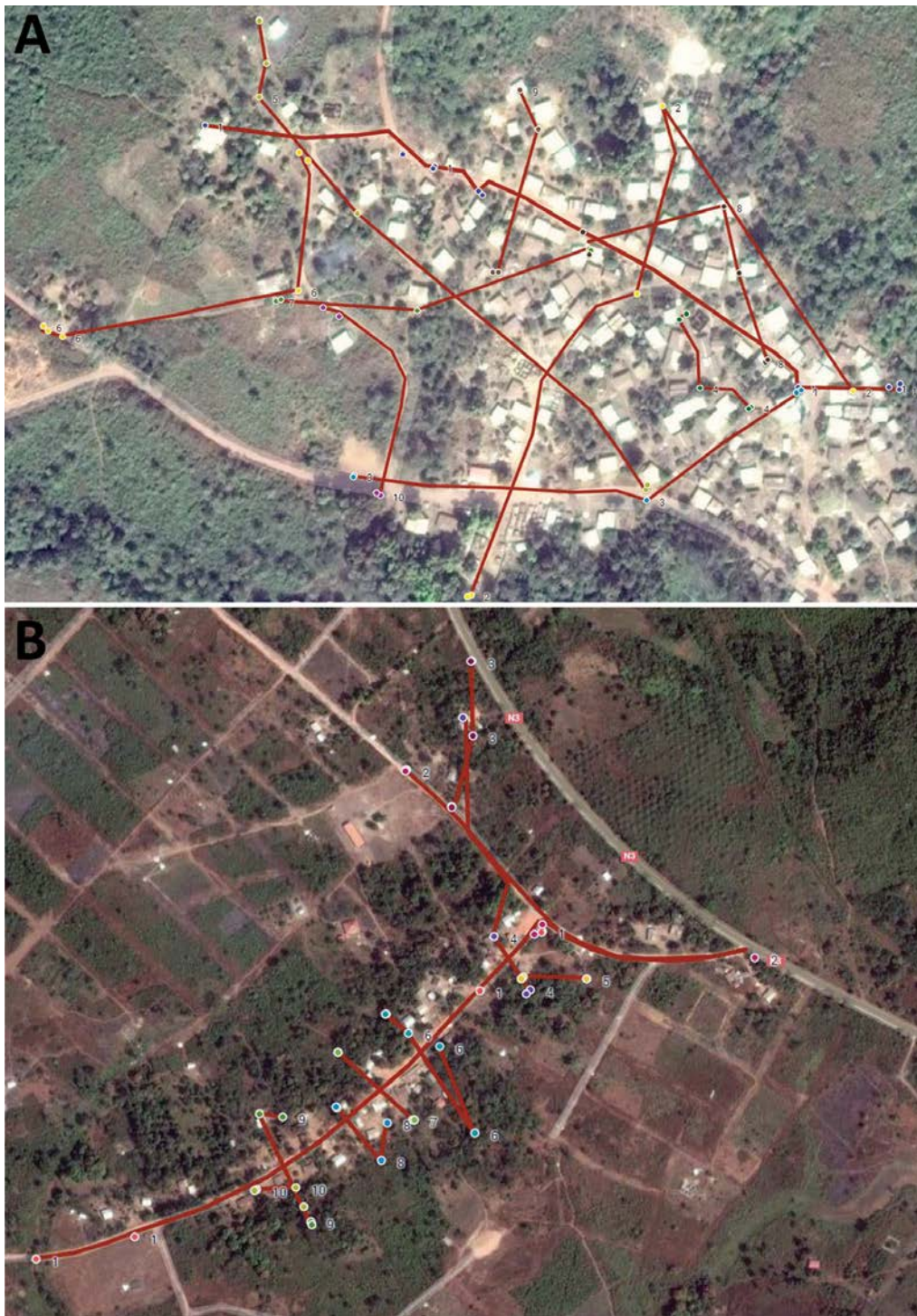
Appendix Figure 1. Average hourly adult female *Anopheles* captured by human landing catches, Conakry, Guinea, 2018. Adult female *Anopheles* mosquitoes were captured for 2 consecutive nights in each commune, with each night simultaneously consisting of indoor (blue bars) and outdoor (dark gray bars) captures. Data are shown for 5 communes of Conakry: Kaloum (A); Dixinn (B); Matam (C); Matoto (D); Ratoma (E).



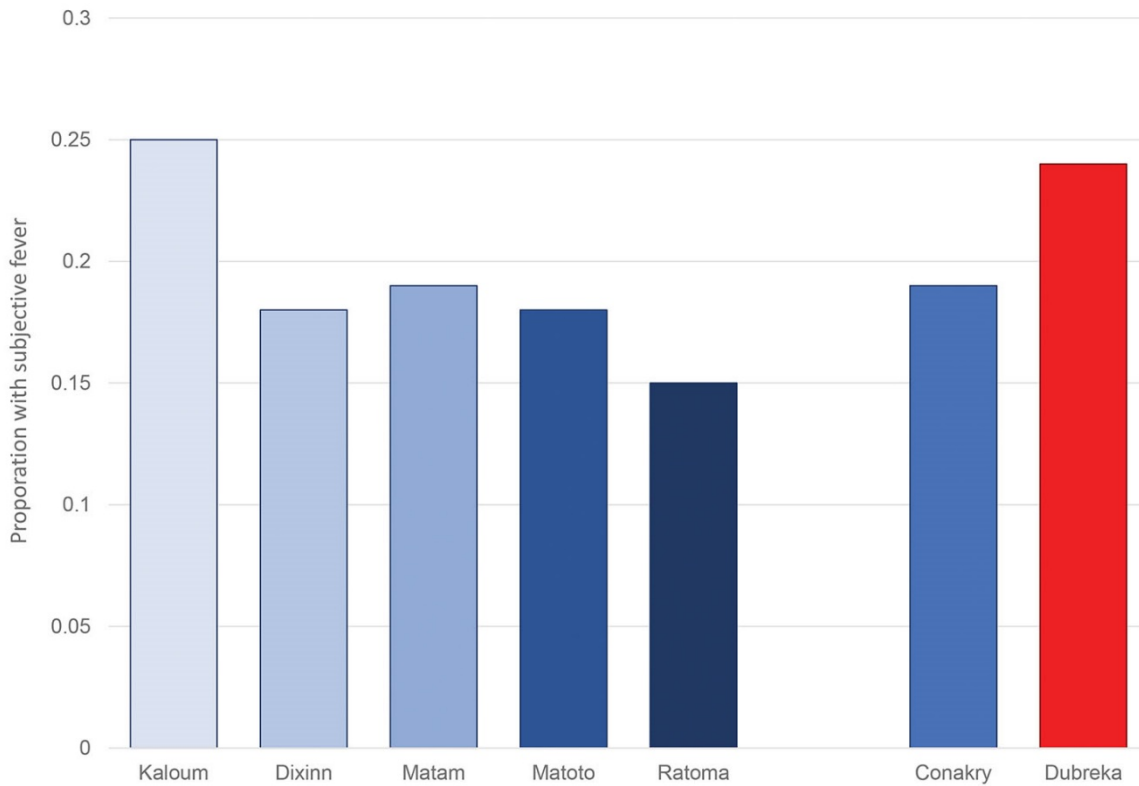
Appendix Figure 2. Average hourly adult female *Anopheles* captured by human landing catches, Dubréka, 2018. Adult female *Anopheles* mosquitoes were collected for 2 consecutive nights in each selected site, with each night simultaneously consisting of indoor (blue bars) and outdoor (dark gray bars) captures. Data are shown for 2 villages in Dubréka: Gbantama (A) and Falessade (B).



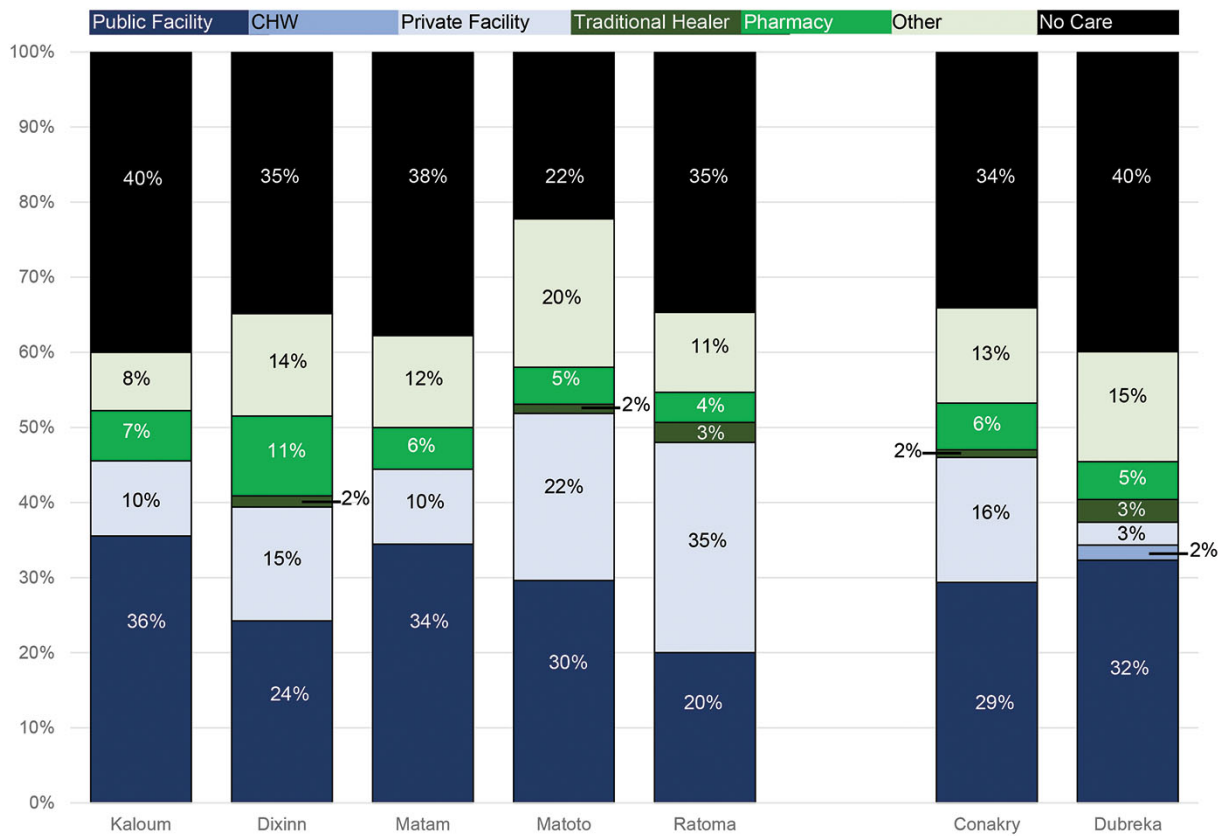
Appendix Figure 3. Urban search areas used for mosquito larval habitat sampling during combined epidemiologic–entomologic investigation, Conakry, Guinea, 2018. Polygons demarcate borders of the zones defined for the exhaustive search for potential larval habits. Mosquito icons denote the presence of collections of standing water, with the color representing mosquito larvae present: black, none; blue, *Culex*; yellow, *Aedes*; red, *Anopheles*. Data are shown for 5 communes of Conakry: Kaloum (A); Dixinn (B); Matam (C); Matoto (D); Ratoma (E).



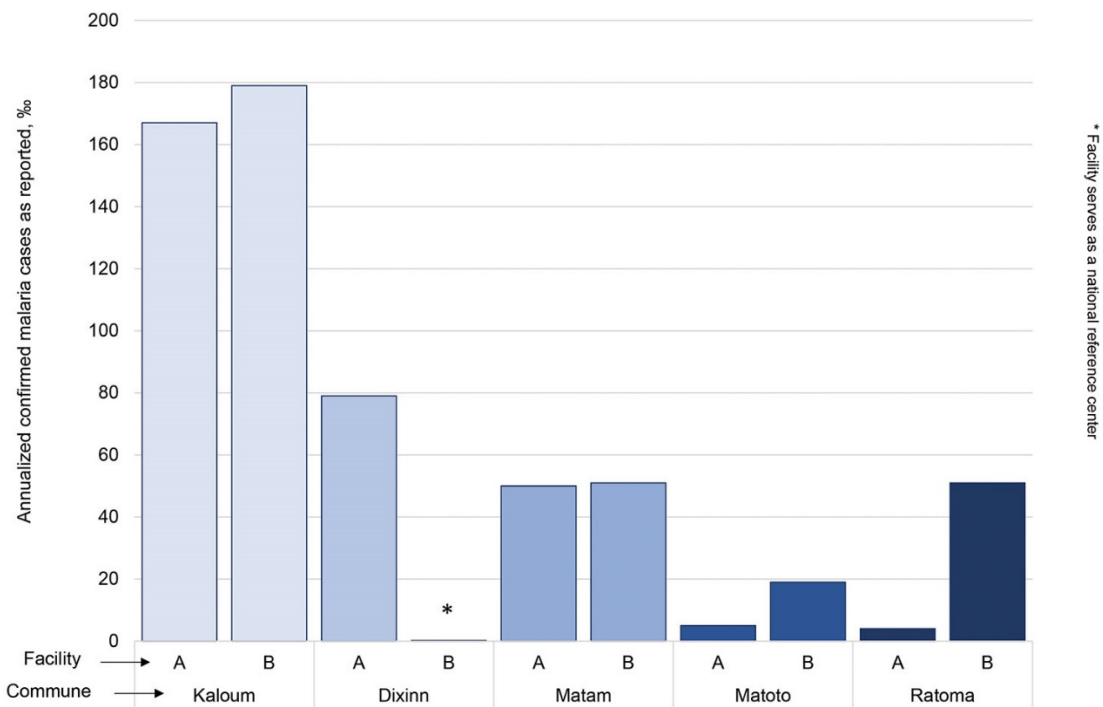
Appendix Figure 4. Village transects used for mosquito larval habitat sampling during combined epidemiologic/entomological investigation, Dubréka, Guinea, 2018. A) Transects used on December 3, 2018, Falessade; 3.230 km total. B) Transects used on December 4, 2018, Gbantama, 2.815 km total. Red lines represent transects walked during the search for potential larval habits. Locations of potential larval habits are not pictured.



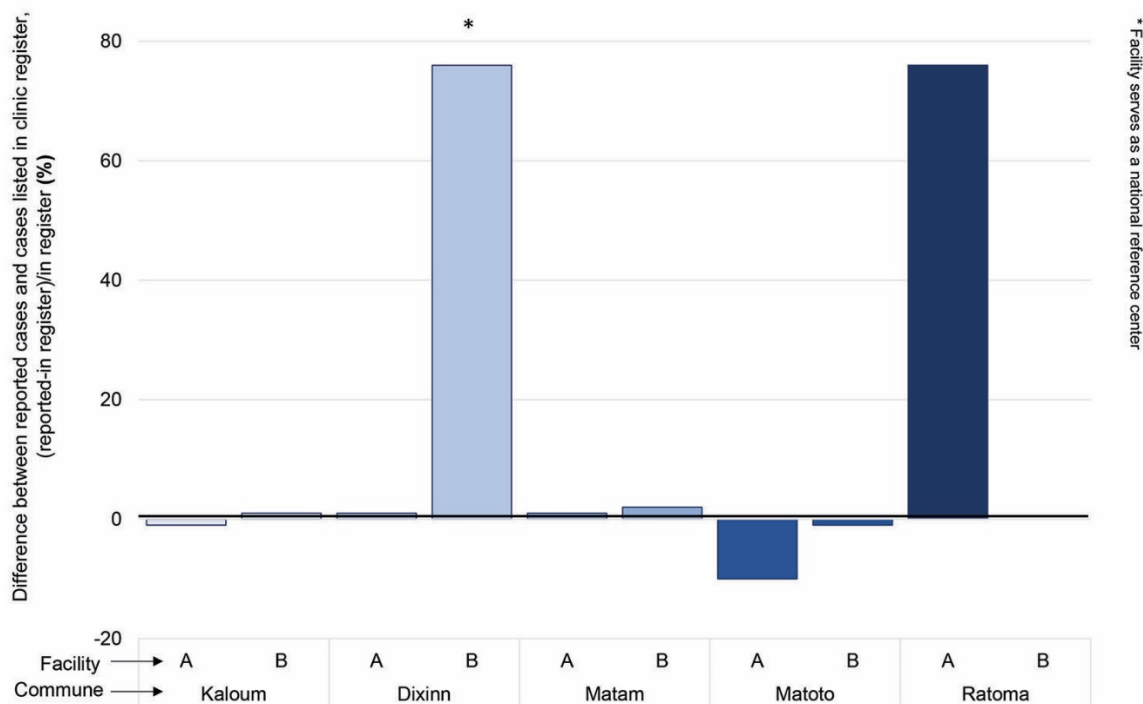
Appendix Figure 5. Proportion of respondents reporting fever within last 2 weeks as assessed by household questionnaire during combined epidemiologic–entomologic investigation of urban malaria transmission, Guinea, 2018. Results by commune of Conakry are depicted on the left, and overall estimates for Conakry and Dubréka on the right.



Appendix Figure 6. Distribution of persons seeking healthcare for fever in last 2 weeks as determined by self-report during rapid epidemiologic–entomologic investigation in Conakry and Dubréka, Guinea, 2018. Distributions of individual urban communes of Conakry are presented on the left; distributions of Conakry as a whole and Dubréka are on the right.



Appendix Figure 7. Malaria incidence in selected healthcare facilities in Conakry, Guinea, July–September 2018. Data were reported by routine surveillance and annualized per 1,000 population.



Appendix Figure 8. Comparison of health facility reported cases of malaria by routine surveillance and those listed in clinical registers, Conakry, Guinea, July –September 2018.