Am. J. Trop. Med. Hyg., 74(1), 2006, pp. 44–53

DISTRIBUTION, DESCRIPTION, AND LOCAL KNOWLEDGE OF LARVAL HABITATS OF *ANOPHELES GAMBIAE* S.L. IN A VILLAGE IN WESTERN KENYA

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Abstract. A sampling census revealed 104 aquatic habitats of 6 types for *Anopheles gambiae* s.l. larvae in a village in western Kenya, namely burrow pits, drainage channels, livestock hoof prints, rain pools, tire tracks, and pools in streambeds. Most habitats were created by human activity and were highly clustered in dispersion pattern within the village landscape. Landscape analysis revealed that six of forty-seven 0.09 km^2 cells superimposed over the village harbored 65% of all habitats. Focus group discussions and in-depth interviews with villagers revealed the extent of knowledge of the village residents of larval habitats, mosquito sources in the local environment, and what might be done to prevent mosquito breeding. Participants did not associate specific habitats with anopheline larvae, expressed reluctance to eliminate habitats because they were sources of domestic water supply, but indicated willingness to participate in a source reduction program if support were available.

INTRODUCTION

Human activities associated with settlement, agriculture, or other environmental alterations may increase larval habitats of anopheline malaria vectors.[1,2] Larvae of *Anopheles gambiae*, the principal vector of malaria in tropical Africa, inhabit small water bodies that are often numerous, scattered, sunlit, turbid, temporary, and close to human dwellings.[3,4] Control strategies for African malaria mosquitoes largely involve methods that kill or deter adult mosquitoes.[5] These strategies include promoting the use of insecticide-treated bed nets (ITNs) and indoor residual spraying (IRS). These tools, when properly applied, have great impact on malaria morbidity and all-cause mortality. But like every known malaria control measure, they have their drawbacks, as illustrated by the emergence of insecticide resistance[6,7] and difficulties in attaining adequate population coverage.[8,9] Additional methods for reducing transmission of malaria—particularly those that might complement existing antiadult methods—are sorely needed for *An. gambiae.*

Control of *An. gambiae* s.l. through environmental control has succeeded in several parts of the world. Source reduction activities in Zambia seven decades ago reduced malaria incidence by 50%.[10] Eradication of introduced *An. gambiae* s.l. from the northeast coast of Brazil and the Nile valley of Egypt[11] via antilarval measures provide additional examples where source reduction was successful. These programs were vertical (i.e., instigated and organized from social levels above that of the local community), focused, and well funded. Horizontally organized programs (i.e., community-based ones) involving elimination of larval habitats or rendering of such habitats unsuitable for larval development will likely require community participation, local resources, and integration of malaria control with broader public health efforts such as sanitation.[1,10,12] The health benefits of these approaches to vector control may not be readily recognized by community members.[12] As noted by Service,[13] "people are resistant to change, especially if they cannot see any immediate rewards or direct benefits it will bring."

The major challenges to community involvement in larval source reduction activities are in educating people about the sources of the mosquitoes and motivating people to assume responsibility for controlling mosquitoes in and around their homes,[13,14] responsibilities often assumed to be that of government. Some governments, for example Singapore, strictly enforce legislation making it unlawful for citizens to allow larval habitats for *Stegomyia aegypti* mosquitoes on private property.[15] Though many people will cooperate with such a program, the motivation for participation is punishment for breaking the law.[14] In contrast, involving the persons who are responsible for creating, maintaining, or using *An. gambiae* s.l. larval habitats may lead to a more effective program. However, there are remarkably few data available on the structure of larval habitats in endemic settings, the knowledge of residents in endemic settings about larval mosquito sources in their environment, nor their specific role in creating such habitats. As a first step in this addressing this deficit, we present here a qualitative study combining habitat census including description, mapping, distribution, and larval presence with focus group discussions (FGD), and in-depth interviews (IDI) conducted in Kisian village, western Kenya. The ultimate goal is to assess community knowledge of larval habitats for *An. gambiae* s.l. and therefore feasibility of community-based interventions to reduce mosquito breeding through source reduction.

MATERIALS AND METHODS

Study site. Kisian village is adjacent to a Kenya Medical Research Institute (KEMRI) research station called the Vector Biology and Control Research Center (VBCRC), 10 km west of the city of Kisumu in Nyanza province in western Kenya (Figure 1). It is located 10 km south of the Equator at an altitude of 1,137 m above sea level. Kisian covers an area of 7.7 km^2 and has a population of 5,412 people.[16] Rainfall occurs year-round with two peaks; the "long rains" falling March–May, and the "short rains" in November–December. Ninety-nine percent of the human population in Kisian is of the Luo ethnic group. Most are subsistence farmers, cultivat-

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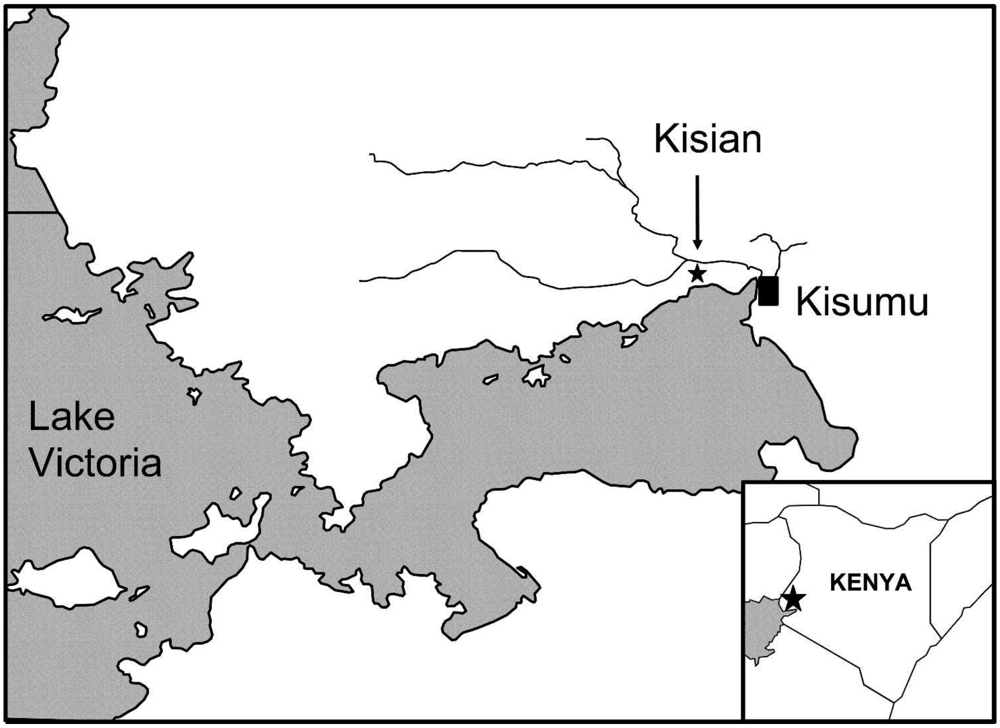

FIGURE 1. Map of western Kenya showing location of Kisian village near Kisumu.

ing maize, sorghum, cassava, millet, and vegetables, and many keep some animals including cattle, goats, sheep, and poultry. Other activities include fishing in Lake Victoria and local marketing of food and grain. Some villagers commute daily to work in Kisumu. Houses are typically constructed of a stick framework with mud walls and a thatch or corrugated metal roof.

Malaria is highly endemic in the region encompassing Kisian, with transmission occurring throughout the year. The mean annual *Plasmodium falciparum* sporozoite inoculation rates range from 90 to 410 infective bites.[17,18] The principal mosquito vectors in the area are *Anopheles gambiae*, *Anopheles funestus* Giles, and *Anopheles arabiensis.*[19] Of the three malaria vectors, *An. gambiae* s.l. and *An. funestus* are highly endophagic and anthropophagic. *An. arabiensis* is largely zoophagic but endophilic.[3,20] Malaria-associated anemia is a serious cause of morbidity and mortality in the region.[21]

Larval habitat census. A census of the larval habitats of *An. gambiae* and *An. arabiensis* was conducted within the geographic limits of Kisian, excluding the VBCRC compound, in November 2002.[22] The entire village was surveyed by a team of workers on foot. The workers operated geopositioning equipment (GPS) during the survey. Features of the village landscape (location of houses, roads, trails, streams, fields, pastures, schools) were located with GPS, assigning coordinates of latitude and longitude to these features. Data were incorporated into a geographic information systems (GIS) map of the study area. All surface waters were also mapped and were sampled by eye, with a mosquito dipper, and by hand with a pipette to determine presence or absence of immature mosquitoes. Mosquitoes were retained and identified to either *Culex* spp. or *Anopheles* spp. Late instar larvae in the genus *Anopheles* were identified to species group.

Inclusion criteria and study tools. Focus group discussions were conducted to obtain information on the villagers' knowledge of mosquito habitat types, the human activities associated with them, and the feasibility of community-based interventions to reduce mosquito breeding and malaria transmission. In-depth interviews were used as a follow-up tool to augment focus group discussions for purposes of clarification. The focus group discussion is a qualitative method for assessment of perceptions and general knowledge, in a format where a facilitator prompts participants to discuss the topic without answering a specific set of questions. A recorder takes notes of the discussion and later summarizes them in categorical form. As a qualitative tool, the focus group discussion system does not lend itself to quantitative analysis yet it typically precedes a quantitative study, in particular one in which a public health intervention is contemplated.[23]

Description of larval habitat formation and origination was accomplished by visual inspection and by discussion with local residents. Based on this information, question guides were developed for focus group discussions and in-depth interviews. The four topics discussed were 1) participants' knowledge of mosquito biology and larval habitats, 2) participants' perceptions of their role in the creation of larval habitats, 3) people's perceptions of the feasibility of preventing or reducing habitat creation or habitat productivity, and 4) participants' views on the role of the community in source-reduction activities.

Focus group participants were selected from two areas of the study village. Two local traditional birth attendants helped identify participants. On the assumption that 4 focus groups are adequate for a given question,[23] we carried out 8 focus group discussions; 4 for men and 4 for women. Each discussion had between 6 and 12 participants. Because Luo customs limit the freedom of women to speak before men, and that of younger people before their elders, all groups were homogeneous for gender and age. The age sets used were 18–34 and 35–70 years for younger and older generations, respectively. Age and educational level of each participant was recorded. Lapel number tags were used for participant identification. Four in-depth interviews were carried out, targeting 2 men and 2 women over the age of 40 who had lived in the study area for at least 10 years. Studies were conducted in the local language, Dholuo, using the set of question guides translated from English to Dholuo, and checked for accuracy by translating back to English. The guides were pretested to ensure ease of administration and comprehensibility. Trained moderators assisted by note takers, all fluent in Dholuo, led both focus group discussions and in-depth interviews. Discussions and interviews lasted 1 to 1½ hours and were tape recorded to aid transcription of field notes, an activity beginning after each session and completed by the next day.

Field notes were transcribed in English by hand by field staff, checked for consistency by the researcher, and finally typed by the researcher. A manual search of the information generated four themes based on four main questions of interest as summarized in Table 1. For ease of categorization, opinions expressed by different groups and individuals were counted and tabulated to pinpoint areas of convergence or divergence of opinion within and between groups and between focus group discussions and in-depth interviews data. Representative verbatim reports are used to illustrate main findings. Frequencies of responses to questions presented in focus group discussion were compiled for comparative purposes here, despite the qualitative context.

Ethical clearance. Informed consent was obtained from all participants in focus group discussions and in-depth interviews at the beginning of each session. A participant in each focus group discussion signed on behalf of all group members after confirming individual participant consent to participate as a group, and in-depth interviewees each gave individual consents. There were no juvenile participants. Answers were anonymized as to source. The research design and questionnaire were reviewed and approved by the institutional review boards of the Centers for Disease Control and Prevention (Protocol no. 3647: Quantification of human behaviors resulting in formation of larval habitiats of *Anopheles gambiae*) and the Kenya Medical Research Institute (Protocol no. 807: Quantification of human behaviors resulting in formation of larval habitats of *Anopheles gambiae*).

Table 1

Habitat types and mosquito larval prevalence in 104 aquatic habitats surveyed in Kisian village, western Kenya, in November 2002

Habitat type	No. of habitats with anopheline larvae only	No. of habitats with culicine larvae only	No. of habitats with both anopheline and culicine larvae	No. of habitats without larvae	Total (%)
Burrow pits	6	5	18	3	32 (30.8)
Drainage channels	7	4	12	3	26 (25.0)
Rain pools	6	1	8	0	15 (14.4)
Hoof prints	13	0	0	0	13 (12.5)
Tire tracks	3	0	10	2	15 (14.4)
Streambed pools	1	1	1	0	3 (2.9)
Total	36	11	49	8	104 (100)

RESULTS

Habitat census. One hundred four discrete habitats were located, sampled, and mapped during the habitat census in November 2002. Of these, 83% were obviously man-made habitats or livestock-associated habitats, and the remainder was rain pools formed by poor drainage after a rain, and pools in streambeds. The survey showed that 35% of the habitats had anopheline larvae only, 10% had culicine larvae only, 47% had anopheline and culicine larvae together, and 8% did not have any larvae (Table 1). The vast majority of anopheline larvae were *Anopheles gambiae* s.l.; details of species composition are given in a companion paper on quantitative sampling, species composition, and habitat productivity.[23] The habitats encountered were easily classified into 6 main groups, based on appearance, obvious mode of formation, and hydrology (Figure 2) as follows:

1. Burrow pits, sometimes called borrow pits, were created through human activities and were of different sizes and varying depths. Most of the pits were formed when humans had dug into the soil to construct mud walls of houses or to make bricks or pots; and secondarily to impound rainwater for livestock, domestic uses, and garden irrigation.
2. Drainage channels included terraces, ditches, and trenches that humans dug either to prevent soil erosion, to alleviate inundation of cultivated fields, or to divert water from the foundations of houses.
3. Tire tracks were created by vehicles and ox-carts on the dirt roads that transect the study area.
4. Hoof-print aggregations consisted of waterlogged soil in low-lying areas along trails and near streams.
5. Rain pools were shallow natural depressions that retained water after rainfall. They often occurred on or near foot paths.
6. Streambed pools occurred in narrow, seasonally flowing waterways and formed as stagnant pools of water during dry periods but were rare during the wet period in November, when we performed our census in the area, because the streams were flowing.

To assess the dispersion pattern of habitats in the village, a 7×7 grid of cells, each cell being 300 m on a side or 0.09 km^2 cell area, was superimposed on the map; it excluded two cells encompassing the VBCRC compound. The distribution of the habitats as revealed by mapping (Figure 3) and dispersion analysis (Figure 4) showed that habitats were highly aggregated in the village landscape and were not randomly distributed. The mean number of habitats was 2.2/km^2 and the variance was 26.1, giving a variance to mean ratio of 11.9. The dispersion pattern of habitats per cell fit well the negative binomial distribution ($\chi^2 = 0.04$, df $= 1$, $P > 0.50$) with an estimated aggregation index k of 0.37, indicating marked aggregation. The dispersion pattern of habitats did not fit the Poisson distribution ($\chi^2 = 72.6$, df $= 3$, $P < 0.005$), indicating habitats were not randomly distributed. The mean distance from human dwellings of 34 habitats, representing a randomly chosen sample of all habitats in which *An. gambiae* larvae were found, was 18 m (range, 1–35 m).

Participant characteristics. Focus group discussions were conducted from 23 January to 4 February 2003. One male and female discussion was held for each age group in each study site division, resulting in 8 focus group discussions, 4 for men

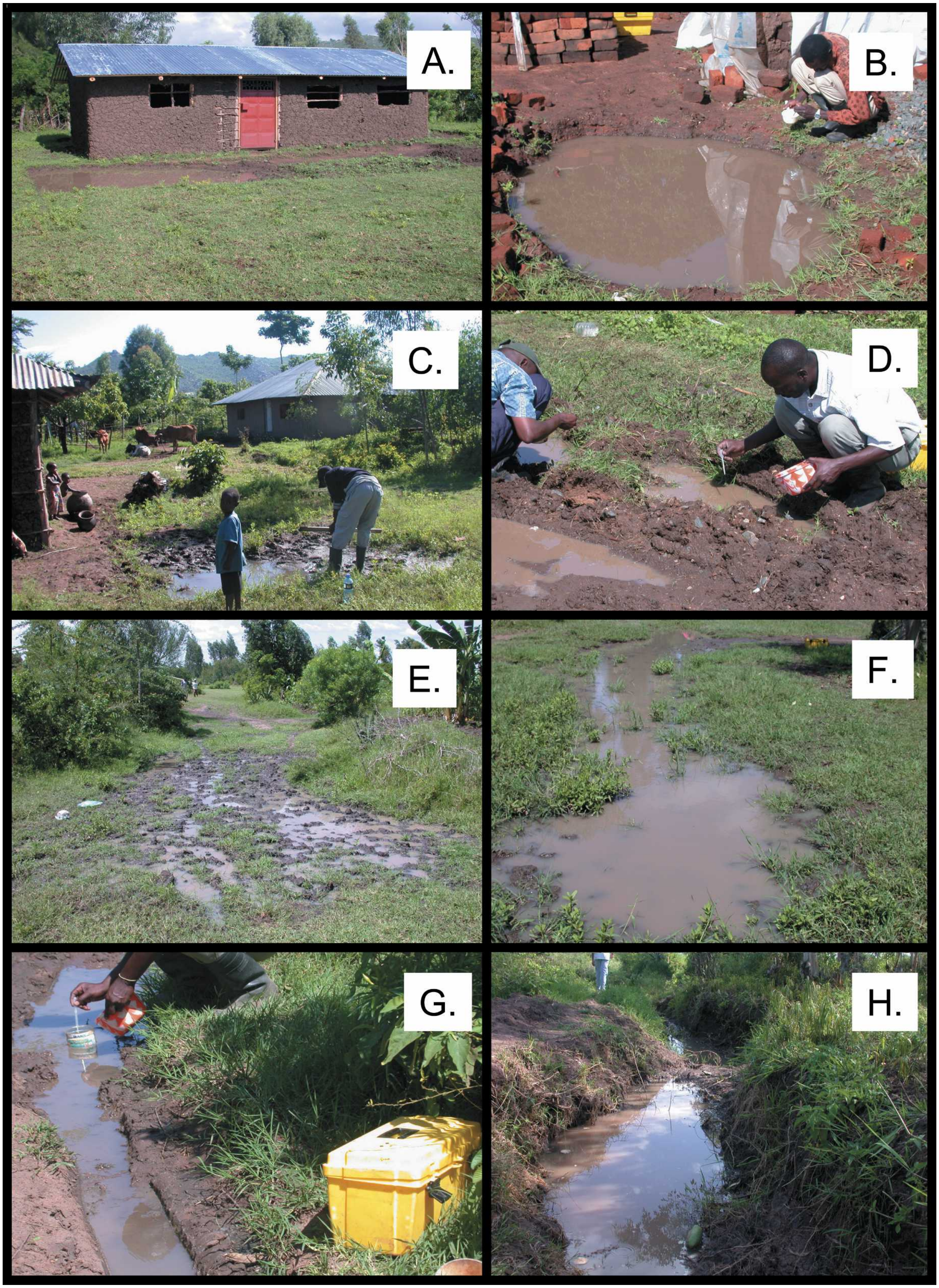

FIGURE 2. Representative habitat types of *Anopheles gambiae* s.l. immatures that were sampled in Kisian, a rural village in western Kenya. **A**, Soil burrow pit dug to mine soil for wall construction of a house. **B**, Burrow pit dug to mine soil to make bricks. **C**, Burrow pit dug for clay soil to make fired pots. **D**, Tire track. **E**, Aggregation of cattle hoof prints. **F**, Natural rain pool. **G**, Drainage channel. **H**, Pool in streambed. This figure appears in color at www.ajtmh.org.

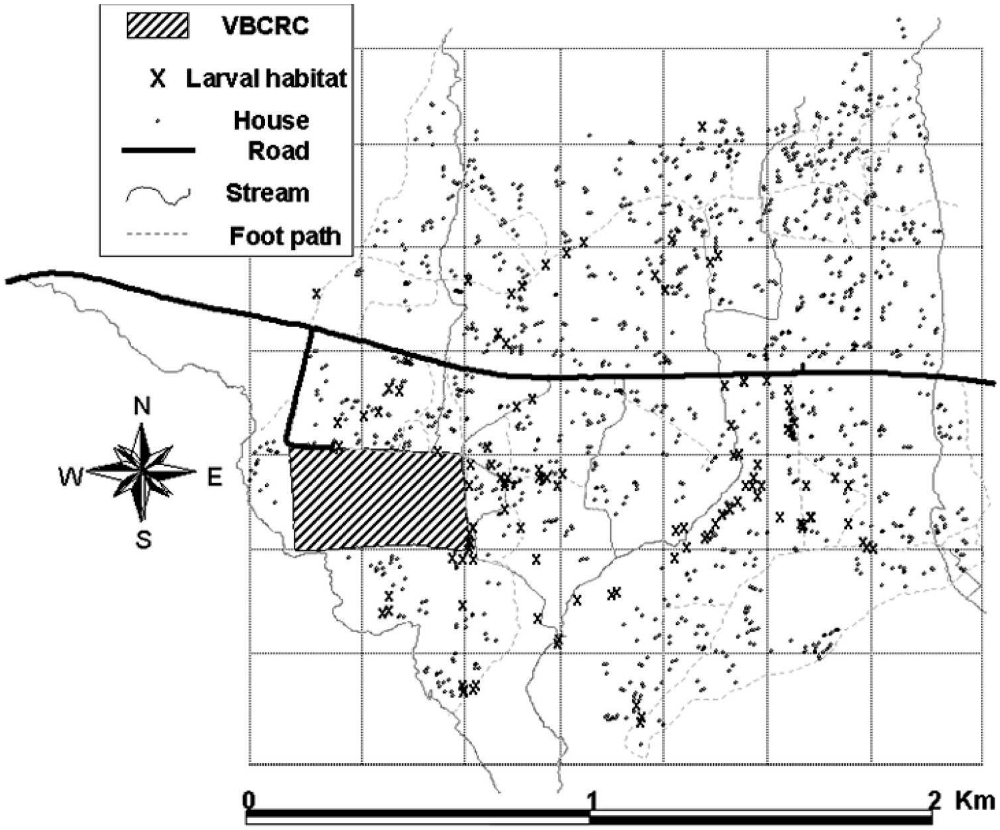

FIGURE 3. Spot and feature GIS map of the village of Kisian in western Kenya, showing distribution and location of larval habitats relative to other landscape features. Grid shows 300 × 300 m (0.09 km^2) cells for habitat distribution analysis. The two cells overlapping with the VBCRC were excluded from the analysis. VBCRC, Vector Biology and Control Research Center.

and 4 for women, with 29 male and 28 female participants, respectively. Group size ranged from 6 to 10 individuals. Younger generation groups had 15 male and 16 female participants, with mean ages of 26.1 and 24.2 years, respectively. The older generation groups had 14 men and 12 women with mean ages of 44.4 and 41.5 years, respectively. Educational levels varied considerably for male and female participants, with males having slightly higher levels of education. The mean years of education in the younger generation was 10.1 and 8.9 for male and female participants, respectively. The difference was larger in the older generation, with men having an average of 9.7 years of education compared with 7.4 for

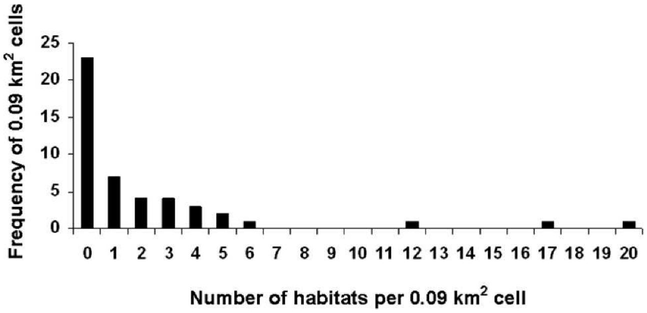

FIGURE 4. Frequency distribution of the number of potential *An. gambiae* larval habitats in 0.09 km^2 cells of the landscape of Kisian, a village in rural western Kenya.

women. There were no major response differences between the age groups and between the sexes. Four in-depth interviews were held with two female and two male interviewees on 6 and 13 February 2003 at interviewees' homes. The overall age for the two females was 40 and 47 years and 7 years of schooling each while the males were 57 and 66 years in age and 11 and 16 years of schooling, respectively.

Knowledge about habitats. All eight focus groups responded to a question about perceived "mosquito" breeding sites, by naming 24 different perceived habitats from a total of 137 individual responses (Tables 2 and 3). We summarized these responses into two categories: habitats created naturally and habitats created through human activity. Within these two categories, habitats were further summarized into three further categories: potential or likely *An. gambiae* s.l. larval habitats, unlikely *An. gambiae* s.l. larval habitats, and entomologically incorrect habitats (Table 3). Most of the responses (61.3%) were categorized as man-made habitats, more than a quarter (29.2%) as naturally occurring habitats, and the remainder (9.5%) were obscure and could not be placed in any of the two categories. Half of the habitats described in the focus group discussions were man-made, about one-quarter were not man-made, and the remaining quarter were entomologically incorrect. Among the entomologically correct habitats, half were potential *An. gambiae* s.l. larval habitats and the other half were unlikely habitats for *An. gambiae* s.l. based on our sampling study, though the latter may have been suitable habitats for non-anopheline mosquitoes, such as container-dwelling species. Similar opinions

TABLE 2

Summary of main themes identified in focus group discussions and in-depth interviews

Knowledge about larval habitats
Twenty-four different perceived habitats types listed in 137 individual responses.
Nine were potential *An. gambiae* s.l. larval habitats; 3 natural and 6 man-made
Nine unlikely to be *An. gambiae* s.l. larval habitats; 3 natural and 6 man-made
Six entomologically incorrect
Indication of inability to detect mosquito breeding in larval habitats
Human role in habitat creation
Human factors clearly noted in creation of larval habitats
Indication that water-use practices are central to well-being, thus some habitat creation is unavoidable
Main contributory factors include making mud dwelling, farming, domestic water use, and transportation
Specific gender domains noted in main contributory factors
Suggestions for preventing creation of larval habitats and mosquito breeding
Larviciding including use of paraffin, diesel oil, and others.
Filling up depressions including pits, tire tracks, terraces, animal hoof prints
General cleanliness in homestead including clearing bushes, cutting grass, and proper disposal of waste containers
Managing water containers by covering or turning upside down when not in use
Intervention design and planning
Active community participation essential, but not easy to attain
General *laissez faire* attitude
Particular reluctance to volunteer services outside of "own home boundaries"
Assistance from government or donors perceived as a prerequisite

emerged in in-depth interviews where 15 habitat types were cited, 4 of which were naturally occurring, 10 man-made, and one was simply listed as stagnant water.

In the in-depth interviews, 40 individual responses listed naturally occurring habitats, but 28 of these were possibly resting places for adult mosquitoes and were not aquatic. Ten responses listed potential *An. gambiae*. s.l. larval habitats, while two were unlikely *An. gambiae* s.l. habitat but possibly were non-anopheline larval habitat, in particular containers. Of four naturally occurring habitats cited in in-depth interviews, only one, rain pools, was a potential *An. gambiae* s.l. larval habitat.

Participants in one focus group perceived wetness as necessary for mosquito breeding, while those in another group showed awareness that some places are simply resting places for adult mosquitoes, for example with the following statement translated from Dholuo: "*Mosquitoes do not breed in bushy places, but only use them as hiding places.*" Although participants thought mosquitoes could breed in water, three focus groups perceived it to be possible only in stagnant water, and not in moving water. One in-depth interviewee suggested mosquitoes are able to breed in flowing water in the river.

Focus group participants identified two man-made habitats as likely sources of mosquitoes: burrow pits, commonly referred to locally as "dug" pits, and drainage channels, locally referred to as "terraces." In-depth interviewees listed these plus two additional habitats: furrows formed by ox-plows and small holes dug by children when playing. Burrow pits were listed in all focus group discussions and in-depth interviews and generated the highest number of individual responses (25 of 137) in the focus group discussions for any single habitat type. Drainage channels, the second most common response, were cited in 6 groups and 2 interviews. Some focus group participants mentioned cowsheds, dark places (e.g., under armchairs indoors), makeshift bathrooms, dirty places, and dustbins as larval habitats. Focus group participants also listed man-made habitats judged unlikely to support mosquito larvae. The most frequently listed habitats were litter (used tins and broken pots) and water containers.

Although at least one potential larval habitat was cited in all 8 focus groups, three-quarters (6 of 8) of the focus groups could not describe what mosquito larvae look like. However, in one-third (11 of 29) of the responses generated, participants appeared able to describe mosquito larvae in water. One participant in a focus group consisting of older men said: "*You will see some tiny black insects moving in the water [we call them young ones of mosquitoes]*." The rest said they had never seen larvae and only believed mosquitoes to breed in particular sites because adult mosquitoes are seen coming out of them or flying around them.

Human role in habitat creation. All 8 focus groups and 4 interviewees agreed that humans create most of the productive habitats. One participant in a focus group consisting of young men said: "*I think it is the human beings who create these habitats because it is they who dig the water pits where there is stagnant water that breeds mosquitoes.*" Human influence was mainly cited in the existence of pits and drainage channels. Burrow pits were said to be dug to harvest soil for making mud walls and to create water reservoirs near homes. Water in the reservoirs was said to be used for washing clothes, bathing, and cooking and sometimes for drinking. Other uses were horticultural, making mud walls and pit latrines, and community projects such as brick making. Drainage channels dug in farms and around houses were also considered an important human activity contributing to habitat creation, mentioned in 5 groups. Drainage channels were said to serve three main uses: preventing rainwater from collecting around houses and damaging walls, preventing damage to crops from water logging, and preventing soil erosion.

Other human activities said to contribute to habitat formation included rainwater retention from roof catchments into barrels and pots, and animal (cattle) keeping, each cited in 3 interviews, and "transportation" cited in 2 focus groups. Cowsheds were said to facilitate mosquito breeding if they were not cleaned regularly, allowed to become overgrown with vegetation, or not provided with a roof. Transportation was thought to create tire tracks in which mosquitoes could breed.

Participants in 6 focus groups and half of in-depth interviewees said that everyone in the community in one way or another contributed to the creation of habitats, but that men and women contribute in different ways. Men as the traditional family heads were said to be mandated to protect all structures in the compound, such as by digging drainage channels around compounds for protection from erosion. If lakes, rivers, or boreholes are located far from homes, men were expected to provide a nearby source from which women may collect water. Women were more likely to be involved in maintenance and preservation of domestic water sources, and less involved in their origination.

TABLE 3

Frequency of responses of focus group discussion participants to questions about their knowledge of larval malaria mosquito habitats in the village environment*

Potential habitats	Total responses (%)	Unlikely habitats	Total responses (%)	Entomologically incorrect	Total responses (%)
		Natural larval habitats			
Rain pools	3 (2.19)	Hollow rocks	1 (0.73)	Tall/wet grass	14 (10.22)
Riverbeds	2 (1.46)	Tree holes	1 (0.73)	Bushy places	14 (10.22)
Swampy places	5 (3.65)				
Total (%)	10 (7.30)		2 (1.46)		28 (20.44)
		Man-made larval habitats			
Water pits (burrow pits)	25 (18.25)	Littering (used tins/pots)	12 (8.76)	Cowsheds	5 (3.65)
Drainage channels	10 (7.29)	Water containers	8 (5.84)	Makeshift bathrooms	1 (0.73)
Tire tracks	6 (4.38)	Open boreholes	5 (3.65)	Dirty places and dustbins	2 (1.46)
Hoof prints	6 (4.38)	Open water tanks	1 (0.73)	Dark places	1 (0.73)
		Holes in tree stumps	1 (0.73)		
		Pit latrines	1 (0.73)		
Total (%)	47 (34.30)		28 (20.44)		9 (6.57)

* Thirteen of 137 responses were obscure and were not tabulated. Three habitat types (ox-plow furrows, tree leaves, and dark places under armchairs) were mentioned only in individual discussions and are not tabulated here.

Preventing habitat creation and mosquito breeding. Participants noted that their water use and farming practices are necessary for survival and not designed to create larval habitats. They suggested that they have engaged in these practices since time immemorial, and that the problem lays in breakdown in past government mosquito control activities. Young participants, perhaps because they are responsible for meeting household water needs, expressed the dilemma posed by attempts to reduce habitat proliferating activities. One interviewee said: "*It is very difficult to drain them [water pits] because this could be the closest source of water . . . better the presence of mosquitoes than the absence of such water pits.*" Nevertheless, it was suggested that larviciding and filling up depressions and pits were possible ways of reducing numbers of larval habitats. Other possible actions included avoiding creating tire tracks and drainage channels, maintaining general compound cleanliness including clearing brush, draining stagnant water, proper waste container disposal, and careful rainwater-harvesting practices. Focus group participants also suggested methods of preventing mosquito biting or preventing malaria transmission such as insecticide-treated bed nets, malaria preventive drugs, and a locally available aerosol spray called "Deadly Doom." Participants in 5 focus groups and 3 in-depth interviews indicated particular appreciation of the role of insecticide-treated bed nets for malaria prevention by protecting people from mosquito bites but also potentially deterring mosquito breeding. One participant in a focus group consisting of elderly women said: "*To some extent nets prevent breeding of mosquitoes because when mosquitoes drop on treated nets, they die and for those that die it is the end of their breeding.*" Other suggested methods listed in this category included mixing cow dung and herbs and burning them to produce smoke to ward off mosquitoes.

Focus group participants suggested spraying of chemical compounds such as diesel, paraffin, oil, and others in the water to prevent larvae from thriving, in 20 of 133 instances. Larviciding was a widely advocated method, cited in all 8 focus groups and 3 in-depth interviews. One participant in a focus group consisting of young men said: "*I think the best way to prevent mosquito breeding is the use of insecticides that kill the young ones of mosquitoes.*" In-depth interviewees perceived larviciding as most effective, not only killing larvae in the water but also reducing chances for mosquitoes to lay their eggs. People in 4 of 8 of the focus groups indicated that local larval control efforts would be hampered by financial constraints, wasteful use of oil, and lack of spraying equipment. Participants in two focus groups perceived larvicides as potentially harmful. One participant in a focus group consisting of young men said: "*. . . it can help to kill the young ones of mosquitoes but it is harmful to human life.*" Participants observed that external assistance might be required in identifying safe chemicals.

Participants in 6 focus groups and 3 interviewees suggested that pits, tire tracks, drainage channels, and animal hoof prints could be filled up to prevent mosquitoes breeding in them. There was a consensus that water reservoirs and drainage channels on farms could not be filled without dire consequences, including increased difficulty in gathering water or failure of crops due to waterlogging or flooding. In addition, the practicability of filling pits or drainage channels was doubted. One participant said: "*There is no way of getting soil for making the mud walls apart from digging the pits.*" Some participants observed that digging up soil elsewhere to fill up one pit led to the creation of another. Participants also noted that drainage channels, both in the farms and around houses, could not be opened up because excess water would flow into neighboring properties, possibly causing a feud. Though of no apparent use to man, water-filled depressions such as animal hoof prints, tire tracks, and natural pools were perceived as unavoidable, created daily as cattle were fed and grazed, as vehicles plied muddy inroads, and as water pools formed during the rains. These potential habitats were said to exist seasonally, and their effect as mosquito breeding habitat was felt to be minimal. Roads were viewed as public utilities maintained by government, participants thought the only solution to these situations was for the government to at least cover them with murram, a local soil material, if not tarmac. Discussions against the idea of filling pools of water also raised concerns of risk of contracting infectious diseases such as "bilharzia" and typhoid. One young male participant suggested that aquatic animals like frogs and fish could be used as mosquito predators so habitats should not be destroyed.

Most focus groups (6 of 8) strongly felt that clearing compounds of brush and debris would stop mosquito breeding around their homesteads and that it was easy to achieve. One participant in a focus group consisting of young men said: "*Most people always clear their compounds to make them clean and not knowing that they are also reducing the breeding of mosquitoes.*" However, there was reluctance to clear compounds and their surroundings of grass, as they are readily available grazing grounds. Mosquito breeding, deemed seasonal, was perceived a lesser threat to people's livelihoods than loss of grazing area for cattle. Participants in 5 of 8 focus groups suggested burning or burying trash containers as a solution, a view shared by all in-depth interviewees. However, a young female focus group participant said: "*Instead of performing other duties like weeding you spend a lot of time collecting empty plastic containers and burning them*." She and her fellow group members deemed it to be a futile attempt to control mosquitoes, as children quickly brought back such litter while playing. Asked how they could prevent water harvesting and storage containers from facilitating mosquito breeding, participants in 2 focus groups and all 4 interviewees suggested they should always be left empty, turned upside down, or kept inside the house until the return of the rains.

Assistance from government and development organizations. Participants in seven focus groups emphasized that assistance from the government or other organizations such as nongovernmental organizations was vital for source reduction. Assistance was envisaged in the form of health education, distribution of ITNs and antimalarial drugs, provision of larvicides, and road maintenance. Staff at the VBCRC, it was said, could assist in preventing habitat creation and mosquito breeding because they have knowledge of where and how mosquitoes breed. Importantly, government assistance was perceived as essential because any activity to prevent habitat creation and mosquito breeding would cover habitats in public spaces like roads and markets.

DISCUSSION

This study is part of our effort in western Kenya[22] to better understand the distribution, abundance, and productivity of *An. gambiae* s.l. larval habitats so as to design source-reduction interventions for malaria control. Most studies of larval habitats of *An. gambiae* s.l. focus on their biologic or physical attributes,[3,4,24] but few have investigated in detail the role of human behavior in their creation or human attitudes about them. Our study aimed to achieve a better understanding of the sociobehavioral factors associated with larval habitat existence and to learn about the views of villagers regarding larval ecology of malaria mosquitoes. Habitat census was combined with qualitative methods drawing from applied anthropology, including focus group discussions and in-depth interviews, to collect data. We provided considerable detail in the "Results" section to reveal the extent of the knowledge of the local residents and to provide a perspective on the potential for them to participate in a community-based source reduction program.

Most *An. gambiae* habitats in our study area were of human origin, a phenomenon that is well-known in western Kenya and elsewhere in sub-Saharan Africa and is likely part of the overall process of domestic adaptation that some members of the *An. gambiae* species complex exhibit.[1,3,4,19] Of 6 recognizably distinct habitat types in our study village, 4 were associated with activities of humans or domestic animals (soil burrow pits, agricultural drainage channels, tire tracks, and hoof-print aggregations), and 2 were natural in origin (rain pools and pools in streambeds). The latter were prone to disturbance from livestock and to flooding and water movement after heavy rains. The habitats were not particularly abundant within the time frame and season in which the census and mapping was done. They were uneven and highly aggregated in distribution across the village landscape, as indicated by the close fit to the negative binomial distribution (whose properties are well-known to describe an aggregated distribution of data); the relatively low value of the aggregation index k (0.33); the skewed variance to mean ratio; and the lack of fit to the Poisson distribution, whose properties describe a random distribution.[25] Most larval habitats were close to houses, being on average 18 m from dwellings and often much closer. Further, few patches of village landscape contained most of the habitats; six of the 0.09 km^2 cells account for 65% of the total number of habitats encountered in the census in the village proper. Habitat distribution appeared therefore to be a consequence of human activity and the physiographic nature of the human living environment, including drainage patterns. Overall, the census shows that the aggregated nature of habitats, the low number of them, and their proximity to houses taken together ought to enhance feasibility of controlling the larval stages of *An. gambiae* s.l. in villages like Kisian. Elsewhere,[22] we have shown that just a subset of these habitats produces most pupae, narrowing even further those habitats that would have to be included in a source-reduction program.

Most villagers revealed limited knowledge of the life cycle of mosquitoes, as few could identify them or knew of the existence of an obligatory, aquatic, immature stage. The concept of "larval habitat" was often confused with adult resting sites. Given this finding, it is unsurprising that villagers showed no knowledge of the more specialized habitats of larval anophelines. Nonetheless, most villagers recognized that the majority of larval mosquito habitats listed are man-made. Most habitats were associated with core domestic activities including management of water and agricultural resources. Cultivation, domestic water uses, animal husbandry, making mud walls, and transportation were given as the major reasons for the existence of what were classified as larval habitats. Practical and immediate needs for water may force people to diminish the relevance of some habitats to mosquito breeding and malaria transmission, for which the causal link is not easily understood and the immediate benefits of control not so evident. Although rain puddles and car tire tracks could be destroyed without any adverse effects, other small bodies of water that are purposely created and preserved for domestic and farm activities are not so easy to destroy, without an alternative mechanism for providing water closer to communities. Or, methods to prevent mosquito breeding in such pools without affecting domestic water use could be applied and news ones developed. Even then, questions of who should address the problem remain. Nonetheless, because vector control activities are beyond the budgetary capacities of most governments in malaria-endemic areas, community initiative or support is a likely prerequisite for any successful intervention.[12,26]

The concept of community participation has gained popularity in many malaria-control strategies.[27] Larval control is not a new idea[1,10] but has not been often used in Africa in the past because larval source-reduction initiatives have always been seen as expensive and largely associated with the government.[28] The challenge is to change this perception and stimulate community involvement in larval control activities. In concurrence with results of productivity studies done in this study area,[22] burrow pits were found to be important sources of *An. gambiae* s.l. The burrow pits are close to human dwellings, and people are aware that they are a source of adult mosquitoes. Control of burrow pit mosquito production may therefore be feasible. However, controlling the proliferation of the pits themselves is difficult as these may be sources of essential water for domestic use. To follow this approach, one would need to help community members acquire simple water tanks for domestic and agricultural use. This idea would likely be welcomed because it would improve water access while diminishing burrow pit mosquito productivity.[13] Alternatively, a long-lasting treatment that people can apply to pits to stop breeding but not pollute the water could be provided. Development of such a treatment should now be easier because the most productive habitats and the reasons for their creation are known. In our study area, parallel studies show that removal of burrow pit production might reduce the number of *An. gambiae* adults by 85%.[22]

Streambed pools were shown to be important sources of *An. gambiae* during the dry season.[22] Further reductions in vector numbers would thus be attained if streambed pools were targeted during the dry season. Community involvement in controlling breeding in streambed pools may not be as effective because community members did not recognize them as sources of the vector. Should community education on the role of these pools in production of malaria mosquitoes be ineffective, control of streambed pool habitats may require the involvement of ministry of health personnel. The extent to which such a strategy might be effective outside of our particular study village remains to be seen. Kisian village may be sufficiently representative of much of the Lake Victoria basin to allow fairly broad application; whether other parts of the east African savannah are sufficiently similar, environmentally and socially, will require further study.

Residents of Kisian village have some knowledge of mosquito biology and some willingness to assist government workers in control of malaria. As the role of source reduction in areas of Africa endemic for malaria is clearly complementary to interventions aimed at adult mosquitoes, so must a source reduction program rely upon effective partnerships among communities and government, and must take into account the social and behavioral issues of implementation.[29] Our study indicates that this particular community has some of the necessary knowledge, and much of the necessary motivation, to function effectively in such a partnership. An education program, coupled with a knowledge, attitudes, and practices (KAP) analysis of its effect, would extend the qualitative assessment we present here and might possibly lead to a model of how local resources could be mobilized for source-reduction activities in a community-based context.

Received April 21, 2005. Accepted for publication August 11, 2005.

Acknowledgments: The authors thank the people of Kisian for their cooperation and interest. We are grateful to Phillister Achien'g, Jacklyne Odongo, Carren Anyango, Dorothy Ochien'g, Ruth Ohuru, Jecinter Rabilo, Maurice Ombok, and George Olang for assisting in organizing and conducting focus group discussions and in-depth interviews. This work was part of a thesis for Master of Public Health degree at Kenyatta University by F. Mutuku.

Financial support: F. Mutuku was supported by a stipend from a cooperative agreement between the Kenya Medical Research Institute and the Centers for Disease Control and Prevention. The larval habitat census and mapping was supported by NIH grant AI-50703 to E. Walker.

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