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Towards a risk map of malaria for Sri Lanka: the importance of house location relative to vector breeding sites

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Background In Sri Lanka, the major malaria vector *Anopheles culicifacies* breeds in pools formed in streams and river beds and it is likely that people living close to such breeding sites are at higher risk of malaria than people living further away. This study was done to quantify the importance of house location relative to vector breeding sites for the occurrence of malaria in order to assess the usefulness of this parameter in future malaria risk maps. Such risk maps could be important tools for planning efficient malaria control measures.

Methods In a group of seven villages in north central Sri Lanka, malaria cases were compared with community controls for distance from house to breeding sites and a number of other variables, including type of housing construction and use of anti-mosquito measures. The presence of *An. culicifacies* in bedrooms was determined by indoor insecticide spray collections.

Results People living within 750 m of the local stream, which was the established vector-breeding site, were at much higher risk for malaria than people living further away (odds ratio adjusted for confounding by other variables 5.93, 95% CI: 3.50–8.91). Houses close to the stream also had more adult *An. culicifacies* in the bedrooms. Poor housing construction was an independent risk factor for malaria.

Conclusions Risk maps of malaria in Sri Lanka can be based on the location of houses relative to streams and rivers that are potential breeding sites for the malaria vector *An. culicifacies*. A distance of 750 m is suggested as the cut-off point in defining low- and high-risk villages.

Keywords Malaria, Sri Lanka, risk map, *Anopheles culicifacies*

Recently there has been keen interest in mapping malaria distribution and risk. Such maps would make it possible to target control measures at high-risk areas and greatly increase the cost efficiency of malaria control programmes.[1,2] Most risk maps that have been developed so far have used as key inputs climatic models and information on weather data such as rainfall, temperature, and relative humidity, which, to a large extent, determine the survival and reproduction of the vector mosquito and the development of the parasite in the vector.[3,4] Other studies have used different indicators of vector presence, reproduction, and survival, such as vegetation patterns, land use, and soil moisture.[5–7] The environmental and climatic variables are then linked with entomological and epidemiological information to identify geographical areas at high risk for malaria. These have covered either vast areas, such as the efforts to map the malaria risk in Africa[8] or a relatively limited number of villages.[9]

In Sri Lanka, the major vector of malaria, *Anopheles culicifacies*, breeds mainly in pools formed in streams and riverbeds.[10–13] In a series of mark-release recapture experiments on *An. culicifacies* it was shown that this species could travel at least 500 m in one night[14] and that 2–7% of *An. culicifacies* mosquitoes had flown a distance of 2 km to a recapture village within 4–7 days of marking and release.[15] Although the estimation of flight

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ranges has a number of methodological difficulties and depends on the local ecology, it is expected that people living close to the breeding sites would be at higher risk for the disease. A risk map of malaria for Sri Lanka could therefore, in principle, be based on the availability of surface water that has a potential for pool formation during critical periods of the year. However, it is crucial that the demarcation of high-risk areas based on entomological findings is supported by epidemiological evidence. It has been shown that the build-up of *An. culicifacies* in stream-bed pools in the dry season is the essential mechanism that eventually leads to the seasonal peak of human malaria.[16] Two studies in Sri Lanka have tried to estimate the risk of living close to breeding sites. In southern Sri Lanka, residents of houses located close to potential breeding sites had a higher risk for malaria, but only if the house was poorly constructed and provided easy access to mosquitoes.[17] In a study in one village in north central Sri Lanka, living close to the local stream was a risk factor for malaria, although of borderline significance when controlled for a range of other risk factors.[18] In both studies, most houses were located less than 500 m from the breeding site and there was, therefore, a limited contrast between exposed and non-exposed houses. To further investigate the importance of house location relative to established and potential breeding sites we expanded our previous study in one village[18] to seven villages with a larger contrast in distance from houses to breeding sites. The study was done to find out how important distance from house to breeding site is for the occurrence of malaria relative to other potential risk factors. This would then make it possible to decide whether, in Sri Lanka and in countries with similar conditions, risk maps of malaria could be based on this distance parameter.

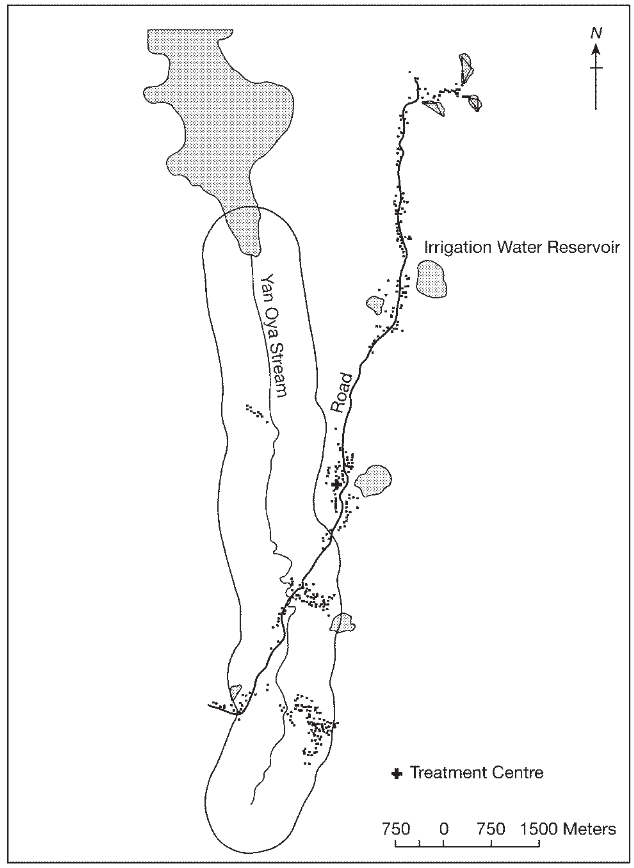

Figure 1 Map of the study area showing the location of all the houses in the seven study villages in relation to the Yan Oya stream, and treatment centre. A buffer of 750 m has been drawn around the Yan Oya stream

Methods

Study area and population

The study was done in seven consecutive villages in the Anuradhapura District of the north central dry zone of Sri Lanka. The study area was located in a malaria-endemic part of the country but with the highly seasonal and annual fluctuating incidence levels typical for Sri Lanka. The landscape of the area was characterized by degraded secondary forest with a main stream, the Yan Oya, and many small water reservoirs (Figure 1). The great majority of the households were engaged in subsistence farming activities using the water from the reservoirs for irrigation of rice fields. Previous studies in the area had shown that the Yan Oya stream was by far the most important breeding site for *An. culicifacies* in this area[16] and that *An. culicifacies* was the most important vector of malaria.[19] The analysis was therefore confined to the stream and did not include distance from houses to other surface water bodies that were present in the area.

Data collection

From May 1996 a malaria research project has attempted to record all cases of malaria occurring in the group of seven villages. To this effect a village-level diagnosis and treatment centre was set up in one village in the study area (Figure 1). This centre became the preferred place for the population to seek diagnosis and treatment for perceived malarial disease.[20] However, a number of people still preferred to visit the government district hospital in Kekirawa located at 25–30 km from the seven villages. From March to April 1996 all houses in the seven villages had been mapped using a global positioning system receiver. While baseline data on malaria risk factors were also collected at that time, it was considered necessary, for the present study, to obtain more recent information on a number of potential risk factors. The use of preventive methods such as bed nets and repellents, and sleeping behaviour can change over time and a recall period of 2 weeks was considered the maximum acceptable for these exposure variables. The present study can therefore be considered a nested case-control study based on complete ascertainment of incident cases within a well-defined population.

Cases were inhabitants of the seven villages who attended the village treatment centre, the district hospital in Kekirawa, or a mobile clinic of the Anti-Malaria Campaign, and who were found to have a blood film positive for malaria parasites between March 1997 and May 1999. Controls were defined as people from the seven villages who did not report an episode of malaria during the previous 2 weeks. The control series was obtained by randomly sampling four people from the census list of the seven villages for each case. Initially four clinic controls were selected from the registries of the health facilities in addition to the community controls. However, this was discontinued in October 1998 when an outbreak of malaria made it logistically impossible to collect the required information within the set time limits and when not enough clinic controls were available for each malaria case. Individuals selected as controls, who later developed malaria were counted as both a control and a case and individuals could be selected more than once as a control.[21] A positive blood film less than 28 days after a previous positive blood film was considered a recrudescence and was not included in the analysis as a new case. Trained field assistants visited the cases and controls at their houses to collect information on a range of exposure variables. A structured questionnaire in the local language was used to obtain information on use of preventive measures and use of anti-malaria drugs in the past 2 weeks for controls and in the 2 weeks before diagnosis for the cases. Parameters pertaining to the type of housing construction and presence of vegetation and cattle sheds near the house were based on direct observations by the interviewer. If a household reported bed net use, the enumerator asked permission to inspect the bed net. Houses were classified as 'good' if they had complete brick walls and a roof of permanent material (tiles, asbestos, or corrugated iron) and as 'poor' if they had incomplete walls, walls made of mud, or a thatched roof. Households were visited up to three times. If the selected person or caretaker was not present at the third visit, any adult household member was questioned about the malaria episode. The maximum time between diagnosis and collection of data was 2 weeks. Regular supervision in the field took place by the authors themselves.

At the treatment centre, as well as at the Kekirawa hospital, all malaria patients received standard treatment with chloroquine and primaquine according to the national guidelines of the Anti-Malaria Campaign of Sri Lanka. According to the same guidelines, patients with a *Plasmodium falciparum* infection were asked to come back after 7 days for a second blood slide reading and if still found positive were given sulphadoxine-pyrimethamine.

The study protocols and ethical aspects of the study were reviewed by the Provincial Director of Health Services. Community meetings were organized in the study area to inform the population and solicit their opinion on the establishment of the treatment centre and the research project associated with it. During the study period the regular malaria control measures of the Anti-Malaria Campaign, including residual house spraying with insecticides, continued.

Mosquito collections

Methods and results of the entomological component of the study will be reported in more detail elsewhere. Briefly, from May 1996 to December 1998 indoor-resting mosquito densities were estimated based on fortnightly collections. For each collection 10% of the houses were randomly sampled in each of the villages. To collect mosquitoes a team of two assistants and one entomologist sampled the room of the selected houses where individuals had been sleeping the night before. After covering all exits, a white cotton sheet was placed on the floor and a pyrethrum-based insecticide was sprayed in the room. Fifteen minutes following the spraying the mosquitoes were collected from the sheet and kept in separate vials for each house. All mosquitoes collected were identified on the same day in the field and recorded by species, gender, and blood meal status for female mosquitoes. In total 2652 spray sheet collections were done in the 473 houses of the seven villages.

Data analysis

For each house the shortest distance to the Yan Oya stream was calculated using ArcInfo geographical information system software (Environmental Systems Research Institute, Redlands, CA, USA). All other analyses were done with SPSS version 8.0. Control for confounding was done with multiple logistic regression.

Results

A total of 219 malaria cases were recorded during the study period, of which 156 had visited the village treatment centre, 59 the District Hospital in Kekirawa, and 4 the mobile clinic of the Anti-Malaria Campaign. Seven cases were excluded from the analysis because they were recorded less than 4 weeks after a previous episode of malaria and the second positive blood film was considered to represent a recrudescence rather than a new infection. Information was obtained from 656 community controls. The 29 community controls that reported the use of anti-malarial drugs in the past 2 weeks were excluded from the analysis. There was a clear difference between cases and controls in the distance from house to the Yan Oya stream (Table 1). Most malaria cases (82%) were living within a distance of 750 m from the stream against only 39% of the controls. There was a clear trend in decreasing number of malaria cases with increasing distance from the stream (χ^2 test for linear trend 117.86, $P < 0.001$).

The association between distance from house to the stream and malaria had a clear biological explanation. In Table 2 odds ratios were defined as the odds of houses positive for

Table 1 Malaria in relation to the distance of house to the established vector-breeding site in seven villages in Sri Lanka

	Cases		Controls			
Distance	n	(%)	n	(%)	**Odds ratio**	**(95% CI)**
<250 m	71	(33.5)	66	(10.6)	13.98	(7.43–26.60)
250–499 m	50	(23.6)	97	(15.5)	6.70	(3.55–12.78)
500–749 m	52	(24.5)	79	(12.6)	8.56	(4.50–16.42)
750–999 m	6	(2.8)	44	(7.0)	1.77	(0.59–5.13)
1000–1249 m	16	(7.5)	118	(18.9)	1.76	(0.81–3.82)
⩾1250 m[a]	17	(8.0)	221	(35.4)	1.00	
Total	212	(100)	625	(100)		

[a] Reference category.

Table 2 Presence of *Anopheles culicifacies* during spray sheet collections in relation to the distance of house to the established vector-breeding site in seven villages in Sri Lanka

	House positive for ANCU[a]		House negative for ANCU			
Distance	n	(%)	n	(%)	**Odds ratio**	**(95% CI)**
<250 m	59	(30.2)	256	(10.4)	7.61	(4.56–12.78)
250–499 m	59	(30.2)	385	(15.7)	5.06	(3.05–8.45)
500–749 m	31	(15.9)	359	(14.6)	2.85	(1.61–5.07)
750–999 m	6	(3.1)	128	(5.2)	1.55	(0.56–4.07)
1000–1249 m	15	(7.7)	503	(20.5)	0.99	(0.49–1.97)
⩾1250 m[b]	25	(12.8)	826	(33.6)	1.00	
Total	195	(100)	2457	(100)		

[a] *Anopheles culicifacies*.
[b] Reference category.

An. culicifacies being located in a certain distance interval divided by the odds of houses negative for *An. culicifacies* being located in the same interval. Houses located close to the Yan Oya stream had a high risk of having *An. culicifacies* in the bedrooms. Adult *An. culicifacies* showed peak abundance during the months of August and September 1998 and preceded a sharp increase in malaria cases during September and October 1998.

In Table 3 distance from houses to stream is listed as a binary variable with 750 m as the cut-off point. Clearly, people living in houses less than 750 m from the stream were at much higher risk for malaria than people living further away. The strong effect of distance from house to stream remained after controlling for a number of potentially confounding variables. Poor housing construction came out as an independent risk factor for malaria and children had a higher risk for malaria than adults. On three occasions the Anti-Malaria Campaign had a programme of residual insecticide spraying in the area. The coverage was high for all the seven villages with between 80% and 95% of the houses covered. In the analysis a distinction was made between the houses that were fully covered during the spray campaigns and houses that had incomplete spray coverage. We also used spraying in the last 30 days as a separate variable (data not shown). In both cases, insecticide spraying did not emerge as a significant variable. Only a very small number of people used bed nets. Less than 40% of the bed nets were impregnated with insecticides and 18% were in poor condition. We did not find

Table 3 Risk factors for malaria in seven villages in Sri Lanka

Variable	Cases	Controls	Odds ratio	(95% CI)	Adjusted odds ratio	(95% CI)
Distance to stream						
<750 m	173	242	7.02	(4.71–10.49)	5.93	(3.50–8.91)
⩾750 m	39	383	1.00		1.00	
Housing construction						
Poor	163	373	2.40	(1.64–3.52)	1.74	(1.14–2.65)
Good	45	247	1.00		1.00	
Distance to cattle shed						
⩾70 m	173	469	1.49	(0.99–2.25)	1.26	(0.81–1.95)
<70 m	39	158	1.00		1.00	
Use of bed nets in last 2 weeks						
Yes	15	44	1.02	(0.53–1.94)	1.56	(0.77–3.17)
No	195	583	1.00		1.00	
Use of pyrethrum coils in last 2 weeks						
Yes	24	110	0.61	(0.37–0.99)	0.60	(0.35–1.02)
No	186	517	1.00		1.00	
Use of traditional fumigants in last 2 weeks						
Yes	41	64	2.13	(1.36–3.34)	1.49	(0.92–2.44)
No	169	563	1.00		1.00	
House sprayed with insecticides						
Yes	186	531	1.29	(0.80–2.12)	1.24	(0.73–2.10)
No or irregular	26	96	1.00		1.00	
Age						
<17 years	124	241	2.49	(1.78–3.50)	1.93	(1.35–2.77)
⩾17 years	79	383	1.00		1.00	
Gender						
Female	100	305	0.95	(0.69–1.32)	1.03	(0.72–1.47)
Male	110	320	1.00		1.00	

a significant protective effect for the few people who used insecticide-treated bed nets that were in good condition. The use of pyrethrum mosquito coils seemed to provide some protection against malaria. The burning of leaves from the neem tree (*Azadirachta indica*) was the most common traditional method for protection against mosquitoes. The use of traditional fumigants came out as a risk factor for malaria in the univariate analysis but this could to a large extent be explained by the location of the houses. People living at less than 750 m from the stream used significantly more traditional fumigants than people living further away ($\chi^2 = 19.36$, $P < 0.001$). People living close to the stream apparently had more nuisance biting mosquitoes in their houses and therefore made more use of traditional fumigants. The usage of bed nets and mosquito coils was not so clearly related to distance of house from the stream. Observations were also recorded on the surroundings of the house, focusing on vegetation that could provide refuge to mosquitoes. Tall grass or bushes close to the house, a poorly maintained home garden, and the presence of trees between the house and the stream were not significant parameters in explaining malaria risk (data not shown).

Discussion

In this study, people living within 750 m of an established vector-breeding site were at much higher risk for malaria than people living further away. It confirms our previous reports[16,19] that in this environment with multiple sources of surface water only the stream is of epidemiological importance. Figure 1 shows the houses in the study area that are within a 750-m buffer around the stream and that are at high risk of malaria. If in a larger area the population living within say, one kilometre of potential breeding sites could be identified, this would allow for cost-efficient control measures.

The association between malaria risk and distance from house to breeding sites has been documented in other parts of the world where different vectors play a role, but it was never as strong as in Sri Lanka.[6,22–24] While in large parts of Africa breeding places of the vector *An. gambiae* are diffuse and various, the breeding places of *An. culicifacies* in Sri Lanka are very much confined to streams. In the Sri Lankan situation one would like to map rivers and streams that have the potential for pooling and superimpose a population distribution map to identify the population at risk. While this would have been a difficult task some years ago, new technologies such as satellite remote sensing and geographical information systems have made it possible to map large areas at low cost. These modern technologies would have to be combined with expert knowledge of malaria control personnel and water resources managers in the field. In general, it is well known by malaria control personnel in Sri Lanka that malaria risk and outbreaks depend heavily upon the dynamics of a relatively small number of rivers and streams.

In addition to rivers and streams there are an estimated 18 000 irrigation reservoirs (tanks) in Sri Lanka. These reservoirs seem less important for the generation of epidemiologically relevant vector mosquitoes than the rivers and streams, but their role has only recently been investigated in more detail.[25]

An alternative explanation for the low number of malaria cases in villages far from the stream could be that people from these villages went for treatment elsewhere. However, based on an intensive study of health-seeking behaviour in the same villages we are confident that this was not the case.[20] Two other hospitals in the area were visited on a regular basis by the researchers to check the records, but no malaria cases were recorded from the study area. Furthermore, the epidemiological results had a clear biological explanation, with an increased risk of having the vector mosquito in the house when the house was located close to the stream. The dispersal range of vector mosquitoes emanating from breeding sites depends on several factors, including wind speed and direction, vegetation pattern, and the fauna, consisting of domestic animals and wildlife to feed on. However, based on the epidemiological data presented, the effective flight range of the vector mosquito can be considered to be less than 1 km.

The study could not describe the protective effects of personal and household malaria control measures very well. The exposure contrast was often small, with few people using bed nets and most houses covered by the insecticide-spraying programme. However, this reflects the actual situation in most of the malaria endemic zones of Sri Lanka. The study found that people living close to the stream used more preventive measures, especially traditional fumigants. We only sampled anopheline mosquitoes but it is likely that more nuisance biting mosquitoes were found close to the stream and that this explained the high usage of preventive measures. Cattle are important blood-meal hosts of anopheline mosquitoes and could either divert mosquitoes away or attract them in larger numbers to human dwellings. This study found no clear effect of distance from house to cattle shed. Our risk estimate for type of housing construction was similar to the one found in another part of Sri Lanka.[17] However, the results of the present study suggest that location of house relative to breeding sites is a more important independent risk factor for malaria.

As expected, malaria was clustered in a relatively small number of households. Twenty-nine individuals had more than one malaria episode recorded during the year and five individuals had three episodes. If there was one month in between two malaria episodes, the second episode was registered as a new case. This time period is rather arbitrary, but we feel that with the clear follow-up procedures it was unlikely that after more than one month it was still the same infection. Prior primaquine treatment also made relapse of *P. vivax* infections less likely.

We have previously described the succession of peaks of *An. culicifacies* larvae, adult mosquitoes, and human malaria cases that occurred in one of the study villages in 1994.[19] After that time, malaria incidence in the study area remained low until the sharp increase during September and October 1998. This illustrates the unstable nature of malaria transmission in Sri Lanka with highly fluctuating incidence from year to year.[13]

Insecticides for malaria control take up a large part of the health budget of Sri Lanka. While the residual spraying programme has already evolved from ‘blanket coverage’ to a stratified approach, spatial targeting with the help of risk maps would further reduce costs. The risk map approach would also be useful for planning of other malaria control measures such as distribution of (impregnated) bed nets, larviciding, and environmental management measures. We have proposed the use of water management for the control of breeding of the vector as a low cost measure.[26] Risk maps would make it possible to combine water management with very focused spraying activities and bed net impregnation programmes. This would be a strong combination of control measures that would have to be applied only part of the year.

In Sri Lanka it seems appropriate to base risk maps for malaria on the location of houses relative to streams and rivers that are potential breeding sites for the vector *An. culicifacies*. The present study suggests the use of a distance of 750 m as cut-off point for a risk map. Once such a risk map is constructed, this measure has to be validated with additional field-level studies. It could then lead to more cost-efficient targeting of control measures, location of treatment facilities, and also find use for decision making in development projects, especially settlement policies.

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