A model of dengue transmission: determination of the threshold of transmission using ovitrap surveillance data in Sarawak, Malaysia

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Abstract

Weekly ovitrap surveillance of *Aedes* vectors was conducted continuously in three urban areas in Kuching, Sarawak to monitor their populations. The possible application of sequential sampling technique to analyse the ovitrap data was examined. The *Aedes* eggs/larvae were found to exhibit a clumped distribution fitted to a negative binomial distribution model without a common K value. The sample size of ovitraps required for decision to control *Aedes* vectors was determined using techniques of sequential sampling and its use in dengue vector control in Malaysia was examined.

Key Words: sequential sampling; ovitraps; *Aedes*; dengue

Introduction

Dengue is the most important mosquito-borne viral disease in Malaysia today. Since the first nation-wide outbreak in 1973, the incidence rate of dengue has been increasing from year to year and by 1995, this was 32.79 per 100,000 (Vector-Borne Diseases Control Programme, unpublished data). The continued occurrence of dengue has thus necessitated the establishment of an efficient system of dengue vector surveillance. In Malaysia, as in many other countries affected by dengue, vector surveillance is dependent on house-to-house larval survey and the data is a measure of the frequency of occurrence of larval breeding. In spite of the extensive use of larval indices (House Index and Breteau Index), the actual vector population threshold of dengue transmission is not known, and in many instances, outbreaks were observed at low vector indices and vice-versa. Recent studies has indicated that dengue outbreak continued to occur despite very low larval population (Lee & Hishamudin, 1990; VBDCP, 1991, unpublished report). The ability to determine this transmission threshold for prediction of an outbreak is therefore highly desirable, as remedial actions can be initiated to prevent it. Lee (1992) in Malaysia, used the ovitrap data and the technique of sequential sampling to determine the vector threshold for dengue transmission. Sequential sampling techniques were developed for quality control in factories in 1943 (Service, 1976). Although its potential use in mosquito population studies was emphasised by Knight (1964), these techniques were mainly used in studying agricultural pests (Danielson & Berry, 1978). Wada *et al.*, (1971) and Mackey & Hoy (1978) successfully applied these techniques to the study of *Culex tritaeniorhynchus* and *Cx. tarsalis* larvae respectively. More recently, Mogi *et al.*,. (1990) also showed the potential of these techniques in the surveillance of *Aedes* vectors in Thailand using ovitraps. In this paper the applicability of sequential sampling technique for determining the threshold of *Aedes* vectors required for dengue transmission in Sarawak is examined.

Materials and Methods

Study area

Three urban areas in Kuching, Sarawak were selected for the study. The selection criteria were the presence of *Aedes* mosquito breeding and frequent reports of cases since 1991. These areas were Kampong Siol Kandis (residential area), Pending Height and Jalan Ang Cheng Ho, both being vacant areas.

Ovitrap

The ovitrap consists of a 300-ml plastic container with straight, slightly tapered sides. The opening measures 7.8 cm in diameter, the base diameter is 6.5 cm and the container is 9.0 cm in height. The outer wall of the container is coated with a layer of black oil paint. Water is added to a level of 5.5 cm and a oviposition paddle (10 cm x 2.5 cm x 0.3 cm) made of hardboard is placed in the water with the rough surface upwards. Each ovitrap was placed indoor and outdoor in 30 randomly selected houses scattered over the study area. The word "indoor" herein is taken to mean the interior of the house, while "outdoor" refers to outside the building but confined to the immediate vicinity of the house. All ovitraps were examined weekly and the paddles were collected individually into paper envelops. Fresh paddles were put and the water level adjusted so that they would remain moist. Ovitraps that were lost or damaged were replaced. Paddles collected were submerged into a bowl of water containing liver powder as larval food. The hatched larvae were subsequently counted and identified at the III instar. The percentage of *Aedes*-positive trap is termed "ovitrap index". Both *Ae. aegypti* and *Ae. albopictus* positive ovitraps data were pooled for calculation since both were confirmed vectors of dengue in Malaysia. The number of hatched larvae is considered equivalent to the number of fertile eggs present in the ovitraps.

Sequential sampling

The decision to initiate *Aedes* control measures can be made by assuming the vector density (average no. larvae/ovitrap) m = m1 when control is not necessary and m= m2 when vector control is deemed necessary. Both m1 and m2 are vector density and their true values can only be established from local disease incidence data. The number of positive samples (Tn) is defined by n, the sample size by the following formulae (Mogi *et al.*, 1990):

if m=m1, then Tn = (A/B) - (C/D) .... (1)

if m =m2, then Tn = (A/B) + (C/D) .... (2)

where A = {*ln* (q1/q2) n}, B = {*ln* (p2q1/p1q2)}, C = {*ln* {(1-(1)/(2)}, and D = {*ln* (p2q1/p1q2)};

where p1 and p2 are proportion of positive samples at m1 and m2 respectively, and q1= 1-p1 and q2= 1-p2. Both p1 and p2 can be obtained from

m= a {-*ln* (1-p)}^{b} ....(3)

without assuming any type of distribution and where a and b are constants (Gerrard & Chiang, 1970). By logarithm, this formula becomes:

ln m= *ln* a + b *ln* {-*ln*(1-p)} ....(4)

The values of a and b can then be determined by the linear regression of ln m against *ln* {-*ln*(1-p)}. $\alpha 1$ and $\alpha 2$ are probabilities of error and both are set at 0.05.

Results

Yearly data from the study areas were obtained and analysed (Table 1-4). The mean number of larvae per trap was variable. If tbe dispersion is fitted by Poisson distribution, then the mean is equal to the variance and departures of $s^2/\bar{x}$ (coefficient of dispersion) from 1 is a measure of the departure from Poisson. The degree of departure from randomness is measured by the index of dispersion (ID). This index is distributed as χ^2 with n-1 degree of freedom. If the dispersion follows Poisson, this index will lie within the χ^2 limit. Throughout the survey period, none of the sample set fitted the Poisson distribution; so that it appeared that the *Aedes* larvae were exhibiting a contagious (aggregated) distribution (Table 1-4). The calculations also indicated a common Kc value for the various areas. Although this value was very close to K′, a trial value of Kc, the value of 1/Ki ($Ki=N/\sum(y'_i/x'_i)$, where $y'_i = s_i^2 - x_i$ and $x'_i = x_i^2 - s_i^2/n_i$), decreased as $1/\bar{x}$ increased (data not shown). Hence the hypothesis of negative binomial distribution with a common K value was not justified in this study. By employing $\bar{x}$ as the estimated sample mean of m, values of the constants a and b were obtained from the linear regression of *ln* m on *ln* {-*ln* (1-p)}. These values were substituted into (1) and (2) for further calculations.

To estimate the threshold of larval population required for transmission, the lowest mean number of larvae (m2) and the incidence of dengue in the study area was examined. Hence the value of m2 can be determined, but not that of m1 (absence of transmission) from the present data. However, it is reasonable to assume that m1 would be lower than m2. Thus when the values of m1 and m2 were known, the corresponding values of p1, q1, p2 and q2 were obtained. Substituting

Table 1. Outdoor ovitrap surveillance of Kampomg Siol Kandis in 1991 and 1992.

Month	Week No.	*$\bar{x}$	s^2	$s^2/\bar{x}$	ID
1991:					
June	1	-	-	-	-
	2	0.7	6.05	8.65	423.61
	3	2.84	4.02	15.85	776.82
July	1	2.08	27.67	13.30	651.78
	2	1.1	13.54	12.31	603.25
	3	2.34	31.81	13.59	666.10
August	1	2.52	26.51	10.40	509.72
	2	5.18	112.78	21.77	1066.88
	3	4.08	60.06	14.72	721.34
September	1	11.4	33.87	2.97	145.59
	2	13.26	89.49	6.75	330.70
	3	13.3	95.76	7.16	350.95
October	1	8.26	97.42	11.79	577.90
	2	11.06	83.72	7.57	370.92
	3	11.38	88.74	7.80	382.08
November	1	12.16	74.30	6.11	299.42
	2	19.28	197.40	10.24	501.70
	3	8.94	95.45	10.68	523.18
December	1	-	-	-	-
	2	9.36	337.09	36.01	1764.68
	3	6.22	39.82	6.40	313.66
1992:					
January	1	4.88	27.04	5.54	271.51
February	1	7.94	68.66	8.57	420.03
	2	7.58	51.41	6.78	332.33
	3	4.94	25.60	5.18	253.96
March	1	6.96	71.40	10.26	502.69
	2	4.72	23.81	5.05	247.00
April	1	5.98	26.63	4.45	218.47
	2	6.52	51.98	7.97	390.68
	3	7.22	37.70	5.22	255.86
May	2	7.36	48.16	6.54	320.65
	3	9.76	89.30	9.15	448.34

*$\bar{x}$ = Mean no. *Aedes* larvae/trap

Table 2. Indoor ovitrap surveillance of Kampomg Siol Kandis in 1991 and 1992.

Month	Week No.	$\bar{x}$	s^2	$s^2/\bar{x}$	ID
1991:					
June	2	2.42	30.25	12.5	612.5
	3	3.66	4.84	7.33	359.33
July	1	3.64	166.15	45.65	2236.66
	2	3.92	149.08	38.03	1863.55
	3	4.14	102.41	24.74	1212.15
August	1	3.1	89.11	28.75	1418.57
	2	3.54	63.04	17.81	872.64
	3	4.14	127.92	30.90	1513.98
September	1	2.06	22.18	10.77	527.68
	2	1.28	14.14	11.05	541.21
	3	1.66	17.39	10.48	513.29
October	1	1.36	14.06	10.34	506.66
	2	1.76	18.15	10.31	505.25
	3	1.78	20.79	11.68	572.41
November	1	2.76	56.25	20.38	998.64
	2	3.2	56.70	17.72	868.23
	3	3.44	54.32	15.79	773.7
December	1	2.18	36.84	16.90	828.17
	2	2.82	53.44	18.95	928.50
	3	0.54	7.40	13.70	671.34
1992:					
January	1	1.78	38.44	21.60	1058.18
	2	0.7	12.53	17.90	877.21
	3	1.2	23.33	19.44	952.60
February	1	1.18	26.63	22.56	1105.64
	2	1.88	26.01	13.84	677.92
	3	2.88	62.57	21.73	1064.53
March	1	2.44	38.69	15.86	776.94
	2	1.98	30.69	15.50	759.54
	3	2.18	27.88	12.79	626.62
April	1	1.28	25.91	20.24	991.79
	2	1.08	14.06	13.02	638.02
	3	1.22	15.76	12.92	633.02
May	1	1.6	22.85	14.28	699.73
	2	0.48	5.66	11.80	578.24
	3	2.16	41.22	19.08	935.00

into (1) and (2), 2 decision lines were obtained and plotted. The decision to initiate vector control or not is determined by examining the number of positive ovitraps. The boundaries of ovitrap for decision to initiate dengue vector control operations (by deploying 30 or 60 traps) are shown in Table 5. There were much year-to-year variations in all the locality. In Kp. Siol Kandis in outdoor surveillance, the threshold of transmission increased from 8% in 1991 to 14% in 1992, whereas in outdoor surveillance, the threshold was reduced from 28% to 8%. Similar variations were also observed in other localities (Table 5).

Table 3: Ovitrap surveillance in Pending Height (vacant land) in 1991 and 1992.

Month	Week No.	$\bar{x}$	s^2	$s^2/\bar{x}$	ID
1991:					
June	1	1.22	25.81	21.15	1036.49
July	1	3.2	61.78	21.15	946.00
	2	2.94	94.67	32.20	1577.88
	3	2.48	38.56	15.55	761.95
August	1	8.62	88.17	10.23	501.21
	2	3.0	10.18	3.39	166.21
	3	3.54	21.44	6.06	296.73
September	1	10.4	75.34	7.24	354.98
	2	13.02	100.80	7.74	379.36
	3	11.9	91.20	7.66	375.54
October	1	8.18	50.41	6.16	301.96
	2	12.36	66.75	5.40	264.62
	3	10.32	70.73	6.85	335.82
November	1	14.14	129.50	9.16	448.78
	2	16.9	166.67	9.86	483.84
	3	14.98	103.43	6.90	338.32
December	1	9.22	177.16	19.21	941.50
	2	3.92	74.30	18.96	928.80
1992:					
January	1	5.64	25.00	4.43	217.20
February	1	10.14	55.655.49		268.93
	2	10.92	52.42	4.80	235.21
	3	5.1	39.31	7.71	377.71
March	2	9.1	105.68	11.61	569.04
	3	6.86	58.37	8.51	416.93
April	1	7.6	37.21	4.90	239.91
	2	6.44	31.58	4.90	240.32
	3	9.84	49.56	5.04	246.80
May	2	7.42	37.58	5.06	248.15
	3	6.88	37.21	5.41	265.01

Discussion

Sequential sampling appears to be a potentially useful technique in making a decision on dengue vector control based on weekly ovitrap data. The present computation indicates that a minimum of 30 ovitraps must be deployed weekly. From our field experience, at least 4 trained staff are required full time. Although the number of lost/damaged ovitrap was minimal (< 5%), it was important to ensure that all traps should be accounted for at each visit, lest they inadvertently became the breeding foci.

The year-to-year variations in the threshold of transmission of a particular locality may reflect the actual efficiency of the vector control operations; for if the threshold is increased, it would imply that a higher vector population density is required to initiate an outbreak, as the original population is now less efficient in transmission due to the effective vector control opera-

Table 4. Ovitrap surveillance in Jalan Ang Cheng Ho in 1991 and 1992.

Month	Week No.	$\bar{x}$	s^2	$s^2/\bar{x}$	ID
1991:					
June	2	0.38	4.75	12.51	612.81
	3	8.78	76.21	8.68	425.33
July	1	5.08	36.24	7.13	349.56
	2	13.54	181.98	13.44	658.57
	3	13.28	76.39	5.75	281.85
August	1	9.88	55.06	5.57	273.05
	2	11.02	86.68	7.87	385.40
	3	11.64	100.20	8.61	421.80
September	1	8.16	34.57	4.24	207.62
	2	6.4	38.94	6.08	298.12
	3	8.98	61.15	6.81	333.68
October	1	12.48	139.95	11.21	549.48
	2	13.92	128.60	9.24	452.67
	3	17.26	144.72	8.38	410.85
November	1	12.14	121.66	10.02	491.05
	2	13.58	115.78	8.53	417.75
	3	12.16	172.92	14.22	696.81
December	1	9.24	86.68	9.38	459.65
	2	6.46	88.36	13.68	670.22
	3	7.34	95.26	12.98	635.92
1992:					
January	1	2.32	32.38	13.96	683.81
	2	1.32	15.21	11.52	564.61
	3	3.18	34.22	10.76	527.33
February	1	9.64	124.32	12.90	631.93
	2	11.18	99.60	8.91	436.53
	3	8.02	122.09	15.34	751.42
March	1	9.94	99.20	9.98	489.02
	2	10.66	161.29	15.13	741.39
	3	11.63	143.28	12.32	603.68
April	1	4.86	53.58	11.63	540.23
	2	2.26	26.32	11.64	570.59
	3	0.6	6.60	11.01	539.40
May	1	5.32	78.15	14.69	719.76
	2	3.74	76.74	20.52	1005.39
	3	6.22	97.02	15.60	764.33

Table 5. Boundaries of ovitrap index required for dengue vector control decision.

Year	Locality	No. ovitrap	OI without vector control	OI with control
1991	Kp.S.Kandis(out)	30	0	8
1992	Kp.S.Kandis(out)	30	10	14
1991	Kp.S.Kandis(in)	30	19	28
1992	Kp.S.Kandis(in)	30	0	8
1991	Pending Height	60	4	9
1992	Pending Height	60	31	61
1991	Jln Ang Cheng Ho	60	14	17
1992	Jln Ang Cheng Ho	60	0	3

tions. Thus, this model can be used not only to determine the transmission threshold, but also as an epidemiological tool to evaluate the effectiveness of dengue vector control operations in the field.

The large number of ovitraps required is primarily due to the fact that m1 and m2 values are set very close. Mogi *et al.*, (1990) have shown that if m1= 2 and m2= 15, then the number of ovitraps required would be 28 per month. They predicted correctly that when the value of m1 approached m2, the sample size required also increased. The actual value of m1 has not been determined but it may be true that in the field m1 and m2 are very close since experience in Singapore has shown that the threshold *Aedes* vector density for dengue transmission was very low (0.2 females per house) (Chan, 1985). However, it is now clear that values of m1 and m2 from a particular study site cannot be generalised and applied to other areas.

The breeding of *Aedes* vectors is also known to be influenced by many other factors. Lee (1990; 1991b) analysed data acquired from nationwide *Aedes* larval surveys in urban towns in Peninsular Malaysia and found that the breeding of *Aedes* larvae was determined by the usage of larvicide (temephos), types, location and the presence of cover of water receptacles and the quality of water. The possible impact of these important limiting factors on ovitrap surveillance using sequential sampling need to be assessed in the Malaysian context.

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