VECTOR DENSITIES AND MALARIA RATES IN THE REPUBLIC OF VIETNAM

RICHARD T. HOLWAY[1]

INTRODUCTION

One of the notable aspects of the malaria problem encountered by the Armed Forces in the Republic of Vietnam has been the seemingly low density of *Anopheles* species known to be effective vectors. This has been the case even in the presence of very high malaria incidence. Actually the vector density as measured by the man-biting rate is comparable to that reported for holoendemic malarious areas in Africa. Most of the survey techniques normally used to study vector populations such as resting station collections, baited traps, house traps, light traps, etc., have not been applicable under the insecure and combat conditions which exist in the areas where malaria is prevalent. As a result the man-biting survey technique has been one of the few methods used for sampling *Anopheles* populations in such areas. Numbers of recognized vectors collected have ranged from 0 to 11 vectors per man per night. A hypothetical model utilizing vector man-biting rates, records of malaria case rates and assumed infective indices has been developed to provide a better understanding of the relative value of personal protection methods in military operations.

MAN-BITING RATE. *Proposition—That the number of vectors which bite one man per night (corrected for excess bites) times 1,000 equals the number of men per thousand bitten by a vector.*

Man-biting collections were initiated in July of 1965 at Danang and Phu Bai in I Corps when it appeared to be the only quick and simple method for determining which species might be significant vectors. The risk of contracting malaria was recognized and precluded extensive use of this method, but volunteers were always available. As of 1969 at least one Navy entomologist and one technician had contracted malaria as a direct result of man-biting collections.

Equipment consisted of a chloroform kill-tube and flashlight (with or without red light, depending on degree of sniper hazard). Originally collections were made by one man who exposed legs and arms and collected all mosquitoes as they fed. A variation consisted of two-man teams in which one man collected from the exposed back of another. Collecting periods varied from 2 to 8 hours with collections divided into time periods in some cases. In the following analysis all data have been corrected to bites per man per 8-hour night.

Table 1 summarizes human biting collection data from I Corps available to the author from July 1965 to October 1966.

The assumed efficient vectors on the basis of reports in the literature are *Anopheles jeyporiensis candidiensis, Anopheles maculatus,* and *Anopheles aconitus.* Notably absent from Table 1 are *Anopheles minimus, Anopheles balabacensis, Anopheles sundaicus* and *Anopheles stephensi* which are known to be efficient vectors in parts of Vietnam. The latter has been taken during 1969 by Stasiak (1969) (personal communication) in several areas of I Corps. Until recently there had been relatively little malaria in the areas of the coastal zone where *Anopheles sinensis* is abundant and more efficient vectors are absent. The extent to which *A. sinensis* may transmit falciparum malaria is still unknown. The Preventive Medicine Unit, Danang, reported 0.36 percent of 2,475 dissections positive for oocysts for Sept.–Nov. 1969, but no sporozoites were detected (Navy Preventive Medicine Unit, NSA, Danang,

[1] U.S. Navy Preventive Medicine Unit No. 6, Box 112, FPO San Francisco 96610.

TABLE 1.—Human biting collections—Victnam.

Place	Time Period	*Anopheles* Species	No/Man Per night	MBR all *Anopheles*	MBR* Good Vectors
		High Malaria Incidence			
Phu Bai, Hill 225	Jul 65	maculatus	5		
		aconitus	6		
		sinensis	2	15	11
		karwari	1		
		philippinensis	1		
Phu Bai, Oasis	Aug 65	maculatus	1.4		
		aconitus	1.4		
		jeyporiensis	2.7	23	5.5
		sinensis	8.1		
		philippinensis	1.4		
		annularis	4		
		peditaeniatus	2.7		
		karwari	1.4		
Chu Lai	Oct 66	jeyporiensis	2.2		
		aconitus	2.2		
		sinensis	3.3	10.7	4.4
		philippinensis	1		
		peditaeniatus	1		
		species	1		
Qui Nhon, Phu Tai Upper Valley	Aug 65	maculatus	2.7	2.7	2.7
BaLong Valley	Oct 65	maculatus	2	2	2
		sinensis	14		
		vagus	2		
		nigerrimus	2		
		Low Malaria Incidence			
Khe Sanh	Dec 65	jeyporiensis	2	4	2
		sinensis	2	(high malaria in 68–69)	
Chu Lai	Apr 66	jeyporiensis	2	12	2
		vagus	2		
		sinensis	8		
Phu Bai "A" Med	Jul 66	vagus	2.6	3.6	0
		sinensis	1		
Qui Nhon, Phu Tai Garrison	Aug 65	karwari	2	6	0
		annularis	2		
		splendidus	2		
Chu Lai 3/7 H&I	May 66	sinensis	1.3	2.7	0
		peditaeniatus	0.7		
		philippinensis	0.7		
Danang, Tien Sha	Dec 65	None	0	0	0
		No Malaria			
Danang	Jul 65	philippinensis	1.5	3.5	0
		vagus	1.5		
		sinensis	0.5		
Chu Lai, Beach	Jul 65	None	0	0	0
Quang Tri Base	Aug 65	sinensis	8	8	0
Phu Bai, Village	Aug 65	peditaeniatus	2.7	75.7	0
		sinensis	73		

* *jeyporiensis candidiensis, maculatus, aconitus.*

1969). A sporozoite rate as high as 2.4 percent has been reported for *A. sinensis* from Indochina but whether this was for *vivax* or *falciparum* is not certain (Gaschen, 1936). It was suggested in 1967 that with continued introduction of *falciparum* reservoirs from hyperendemic areas increased transmission in formerly malaria-free areas might be expected (Holway *et al,* 1967). During the latter part of 1969 reports from I Corps indicate that falciparum malaria is in fact being transmitted more frequently in parts of the coastal zone which have been essentially malaria-free in the past.

The man-biting rate or incidence of bites per inhabitant per day is one of the basic parameters needed to estimate the potential number of malaria cases in a given population. Garett-Jones (1964) proposes a method by which the man-biting rate may be estimated by captures through the night on human baits or indirectly from an index of indoor-resting-blood-fed females per inhabitant. Both methods were compared for *A. gambiae* in Northern Nigeria (Garett-Jones and Shidrawi 1969) and it was concluded that the direct-capture method probably gave an exaggerated index of the true incidence of vector-man contact. A provisional correction factor of 0.33 was applied to compensate for "excess bites."

The situation under military operational conditions in Vietnam is quite different in a number of ways. There is no indoor component or household residual control factor to consider and the human population in the areas of high malaria incidence under consideration is extremely temporary and mobile, but concentrated in small areas. The vector species are different but the availability of non-human hosts is probably quite low as a result of intensive combat activity. A significant factor affecting the observed man-biting rate would be the use of repellents. As host-seeking mosquitoes avoid subjects with repellent, the untreated baits and others would receive a greater number of bites. Surveys of military units over a period of 15 months in 1968–1969 to determine usage of repellent reveal that from 20 percent to 60 percent admit not using repellent. The higher figure is more likely to be applicable prior to 1968 when command emphasis on use of repellents was intensified. Combining a .60 correction factor for effect of repellents on the biting rate with the basic .33 factor estimated by Garett-Jones and Shidrawi (1969) gives an estimated correction for the observed man-biting rate of about 0.2.

It must be noted that the number of bait nights worked was very much limited by existing conditions and does not provide satisfactory sampling. Nevertheless the calculated man-biting rates are not inconsistent with actual malaria case reports when considered in relation to a reasonable range of infective indices and estimated effectiveness of personal protection methods.

Table 1 indicates a range of observed man-biting rates for good vectors of from 2 to 11. This compares with observed rates for *A. gambiae* in Northern Nigeria of from 0.5 to 43.7 as reported by Garett-Jones and Shidrawi (1969); Fox (1957) gives data on all-night catches of *A.gambiae* and *A. melas* showing a mean catch per man night of from 2.5 to 25.

INFECTIVE INDEX. *Proposition—That the percentage of malaria vectors infective to man under conditions of significant malaria transmission will usually range between 0.1% and 10%. This infective index times the number of men bitten by a vector equals the potential malaria inoculation rate per thousand per night.*

The determination of vectorial capacity in modern malaria epidemiology involves the measurement of many factors in addition to the vector density. These include the vector's man-biting habits, expectation of infective life based upon sporogonic period of the parasites, parous age grouping, and other factors. It has not been possible to make any of these measure-

ments in Vietnam, if in fact such methods would be applicable under the existing conditions. It was not even possible to obtain enough specimens from hyperendemic areas for dissections to determine the sporozoite rate and it is doubtful if it would be worth the effort required. Therefore, if any analysis at all is to be made of man-biting rates and malaria incidence it must be a general approximation based upon an assumed infective index. That is, the percentage of total mosquito vector bites on a given military population which are infective.

Although the sporozoite rate and infective index are not necessarily synonymous, it would seem from the above that in an area of active malaria transmission the infective index in the majority of cases would fall between 0.1 and 10 percent.

Figure 1 combines a range of man-biting rates with a range of infective indices to show the potential malaria inoculations per 1,000/day after correction of the observed biting rate by 0.2. It becomes apparent that the biting rates (2–11) observed at a number of localities in RVN would be adequate to account for a

TABLE 2.—Summary of salivary gland dissection reports.

	Total Dissections	Percent Glands Positive	Range of % Where Positive Glands Were Found
jeyporiensis candidiensis	37,650	1.7	0.24 – 5
maculatus	39,200	0.42	0.06 –17
stephensi	8,175	0.95	0.08 –12
aconitus	13,000	0.04	0.1 – 4.2
minimus	218,000	0.82	0.14 – 9
sinensis	23,700	0.11	0.025– 2.4
gambiae	168,170	2.5	0.35 –34

(Adapted from Horsfall).

The infective index will vary greatly as units move in and out of operational areas and obviously will depend upon the presence of personnel capable of infecting the vector, or the time elapsed since the area was vacated by parasite carriers. Reports in the literature of sporozoite rates under conditions of malaria transmission are used herein as a basis for an assumed range of infective indices. Horsfall (1955) has reviewed the findings of a large number of investigators on various species in many parts of the world. Table 2 is a composite summary of the range and percent of salivary glands positive for sporozoites reported for selected species.

Garett-Jones and Shidrawi (1969) report a sporozoite rate for *A. gambiae* in Northern Nigeria of 1.6 percent for August-September and 5.9 percent for October-November in an unsprayed area. potentially high malaria incidence even when the infective index is much less than 1 percent.

MALARIA INCIDENCE. *Proposition—That the malaria incidence is equal to the number of potential inoculations/1000/-night reduced by the percentage effectiveness of combined control by repellents and suppressive drugs.*

Malaria case reports normally cover large units comprising many components scattered over a variety of different localities. Because of the extreme variation in endemicity found in Vietnam, even within short distances, these reports are of little value in considering epidemiology in a specific area. However, there are a number of controlled studies in which small units were stationed in highly malarious areas for limited periods of time and for which good information is available. Some of these are listed in Table 3.

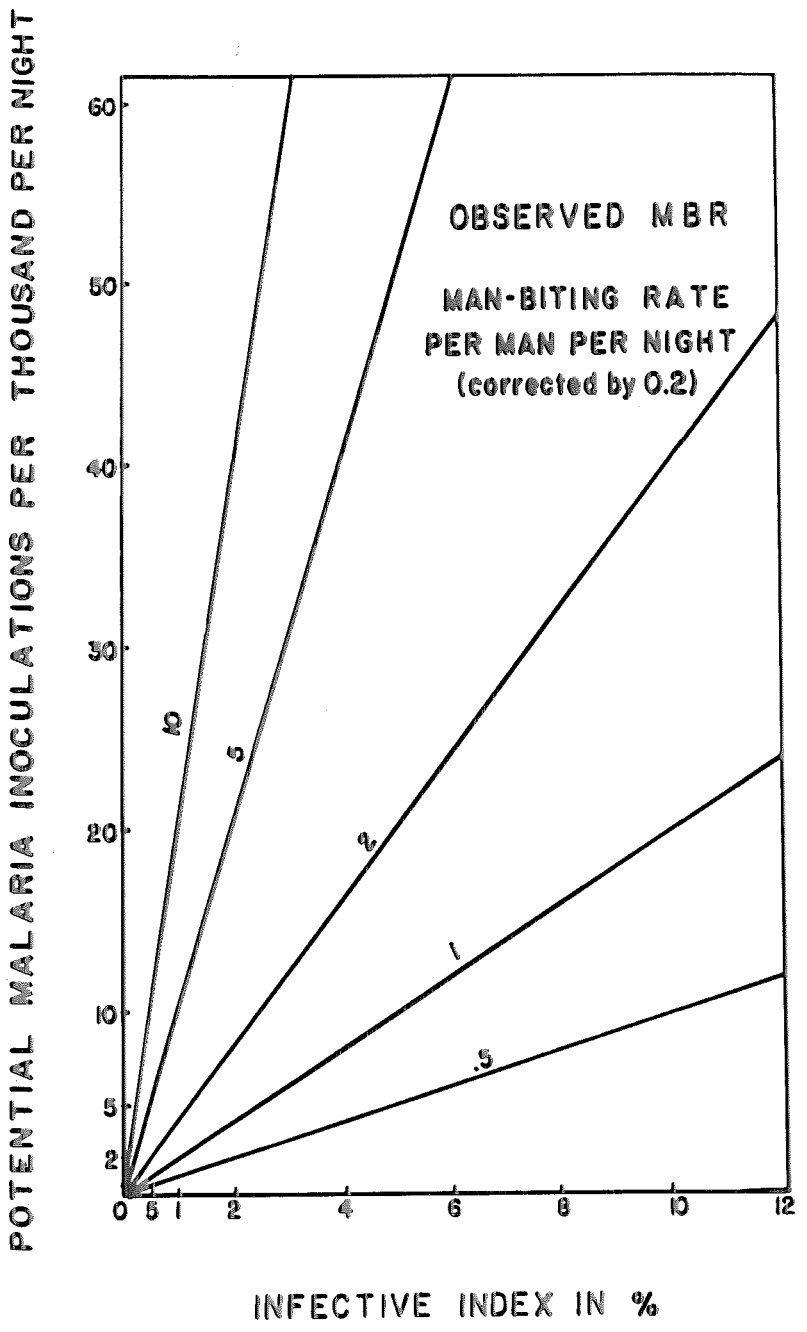

FIG. 1.—Potential malaria inoculations at different vector densities and infective indices.

TABLE 3.—Actual malaria case reports.

Locality	Number Personnel	Days Exposure	Rate/ 1000/ day
BaLong	800	120	8.3
Lang Vie	325	40	8
Rockpile	800	15	3.1
Ken Valley	400	5	53
Army Units Central Highlands *			
1/14 (DDS)	787	26	2
2/35 (DDS)	787	25	1.1
2/12	843	12	12.5
2/5	541	9	18.7
1/35 (DDS)	548	13	1.8

* Data from Joy *et al.*, Mil. Med., 1969.

The first two locations (BaLong and Lang Vie) were occupied by ARVN units and the diagnoses were not fully confirmed by blood smear readings. However, the clinical picture was such that, if anything, the reported rates are too low. The U.S. adviser at BaLong in December 1965 stated that at least 10 percent of this unit was constantly ill with malaria and that 100 percent had experienced at least one attack during a 4-month period. Only "serious" cases were evacuated to the ARVN hospital at Quang Tri and most of these were returned to BaLong as soon as they were free of symptoms. Repellent was not available and suppressive drugs were mostly unavailable or used only sporadically. One man-biting collection in October 1965 produced an MBR of 2 *A. maculatus,* 14 *A. sinensis,* and 4 other *Anopheles* species.

At Lang Vie an ARVN unit established its camp adjacent to the local Montagnard village. After 40 days the malaria rate for this unit was 239/1,000/month (Smith, personal communication, 1966). The degree of use of suppressive drugs and repellents is unknown but was probably not much better than the comparable unit at BaLong. *A. aconitus* and *A. minimus* larvae were taken from the stream surrounding the village and camp area.

The Rockpile and Ken Valley were U.S. Marine operations and the cases were confirmed at a Navy hospital facility. The Rockpile data were studied and reported by a Navy epidemiologist (Adams, personal communication, 1966). Chloroquin-primaquine tablets and repellents were generally available and prescribed but surveys indicate actual use ranged from 40–60 percent. The data for the Army units are taken from Joy *et al.* (1966b) and are based upon a carefully controlled experiment to test the effectiveness of dapsone (4,4 ^{1} Diaminodiphenylsulfone=DDS) as a malaria suppressive.

Man-biting rates are not available for the locations and times corresponding to the above malaria case records with the exception of BaLong. Therefore, a range of possible vector biting rates and infective indices is listed for the hypothetical model in Table 4. Potential inoculations per 1,000/day are given for a variety of possible combinations of MBR and infective indices. An MBR of 2 and index of 2 percent will produce a potential inoculation rate of 8/1000/day and a comparable case rate if effectiveness of suppressive drugs is zero. This is consistent with the actual case reports for BaLong and Lang Vie. Any equivalent of man-biting rates from 2 to 10 with an infective index of from 0.4 to 2 would produce the same potential rate. A 50 percent effectiveness of personal protection would have the same effect as a reduction of 50 percent in either the MBR or the infective index.

The estimation of potential inoculations is, of course, a statistical average based on assumptions as to values as well as an even distribution of bites by infective vectors among the vulnerable personnel.

To what extent are potential malaria inoculations or cases reduced by the use of personal protection methods? The two important methods are repellents and chemosuppressive drugs. Before attempting to estimate the combined effectiveness, it is necessary to examine each method in detail.

REPELLENTS. *Proposition—That mosquitoes will continue seeking a blood meal*

TABLE 4.—Potential malaria in relation to vector density.

Hypothetical Model MBR* x .2 x infective index x 1,000=potential inoculations/1,000/day						
Assumed MBR*	Assumed Infective Index (%)	Potential Inoculations per 1,000/day	Potential cases reduced by % effectiveness of combined repellent and drug control 20%	50%	70%	90%
10	0.1					
2	0.5	2	1.6	1	0.6	0.2
2	1	4	3.2	2	1.2	0.4
2	2	8	6.4	4	2.4	0.8
5	1	10	8	5	3	1
10	1					
2	5	20	16	10	6	2
5	3	30	24	15	9	3
2	10	40	32	20	12	4
5	5	50	40	25	15	5
10	5	100	80	50	30	10
10	10	200	160	100	60	20

* Man-biting rate=number of observed bites per man per night.

until an unprotected host is found. Therefore, ten infective vectors will produce ten potential inoculations per thousand even though only 100 out of 1,000 men are vulnerable to mosquito bites. Adequate use of repellents will provide positive protection to the individual user but it will not reduce actual malaria rates significantly unless total usage is greater than 90 percent and multiple bites may be expected.

Effective use of repellents, nets and protective clothing will prevent mosquito bites and it is usually assumed that malaria rates will be reduced in proportion to use of such measures. In fact, the overall rate is not reduced proportionally although the individual user is positively protected. Table 5 illustrates the theoretical effect of personal protection (repellent, nets, clothing) on potential cases when the number of infective vectors is 10 per 1,000 per night. If 90 percent of the unit use protective methods effectively there will still be 100 vulnerable men and a potential case rate of 10/1,000. The effect of the 90 percent repellent use is to reduce the initial chances of multiple bites from 1 in 100 to 1 in 10. At 99 percent utilization there would be 10 infective mosquitoes to 10 vulnerable men. In this situation there would almost certainly be some multiple inoculations with consequent reduction in the overall rate to perhaps 5 to 8 cases per 1,000/night.

A number of unknown and unmeasurable factors such as differences in individual attractiveness and location of individuals with respect to infiltrating mosquitoes

TABLE 5.—Effect of personal protection and multiple infective bites on malaria incidence.

Percent Protected	Number of Vulnerable Men i.e.—No repellents or nets	Chances of Multiple Bites	Absence of Multiple Bites	Number of Potential Cases/1000/night* 1 Man 2 Bites	2 Men 2 Bites	5 Men 2 Bites	2 Men 5 Bites	1 Man 10 Bites
0	1000	1–100	10	9	8	5	2	1
50	500	1–50	10	9	8	5	2	1
90	100	1–10	10	9	8	5	2	1
99	10	1–1	10	9	8	5	2	1
99.90	1		1	1	1	1	1	1

* When total number of infective vectors is 10, based on assumed man-biting rate of 5 per man per night (corrected by 0.2) and an infective index of 1 percent.

will affect the statistical chances of multiple bites. At 90 percent usage of personal protection the number of potential cases per 1,000 per night would be reduced only slightly, with perhaps reduction to 80 percent the best that could be expected. Presumably, the 1–10 chance of multiple bites would be increased by the unknown factors referred to above. However, there have been no studies to indicate that individual differences in attractiveness are so great that any one man is so potent an attractant that he could draw all mosquitoes to himself and away from all other potential hosts.

During 1968 and 1969 some information on the use of repellents in I Corps has been obtained by interviews with malaria patients. An average of several hundred men per month were questioned by preventive medicine personnel. The number of patients admitting that they had *not* used repellents ranged from 28 to 56 percent with an average of 43 percent per month (PMU Danang, 1969). It is well known that many men will hesitate to admit that they have failed to observe malaria discipline so that these figures must be assumed to represent maximum degree of utilization. Furthermore, application of repellent is often deficient in thoroughness or frequency so that effective use probably averaged less than 60 percent during this period. The use of nets and protective clothing is rarely a significant factor under patrol and combat situations. In summary, it appears that until the use rate exceeds 90 percent there is a small probability that malaria case rates would be reduced significantly even though the individual user may be fully protected.

CHEMOPROPHYLAXIS. *Proposition—That there is a constant relationship between the total drugs use rate, the percent of malaria cases which has taken drugs regularly, and the failure rate of the drug. It follows that if the total drug use rate and the percent of cases on drugs are known the failure rate may be calculated.*

It is axiomatic that the success of chemoprophylaxis in suppression of malaria depends upon adequate usage of the drug by the individual as well as effectiveness of drug action on the parasite. Obviously, a variable amount of failure occurs on both counts but the degree of this failure has not been subject to accurate measurement. It is now well known that drugs often fail to suppress malaria even when taken regularly in prescribed doses. Numerous causes have been demonstrated or suggested such as parasite resistance, failure to absorb before elimination, and overwhelming of the drug's potential by massive parasite inoculations. Medical officers in I Corps have considered chloroquin-primaquine to be about 60–80 percent effective against falciparum malaria and almost 100 percent effective against vivax (Scholdt, mimeo report, 1968). Joy *et al.* (1969) uses the relationship between number of malaria patients with adequate intake of a CP-placebo and the corresponding number of a group using dapsone to show a significant advantage of dapsone over CP.

If any drug is 100 percent effective the number of patients who had been on an adequate drug regimen should be zero. Conversely, if the drug is totally ineffective the malaria rate for drug users should be the same as that for non-users. Thus, if there is a proportional distribution of infective bites between users and non-users (and there is no reason to expect this would not be the case within limits of normal variation due to chance) there must be a constant relationship between the total percentage of drug users, the percentage of malaria cases who have been on drugs, and the percentage failure of the drug. This relationship holds regardless of the number of infective vectors. It may be expressed as a model (figure 2) constructed from the following parameters and formula:

Total drug use rate	d
Total drug non-use rate (1-d)	n
Malaria case drug use rate	m

$$f = \frac{nm}{d\text{-}dm}$$

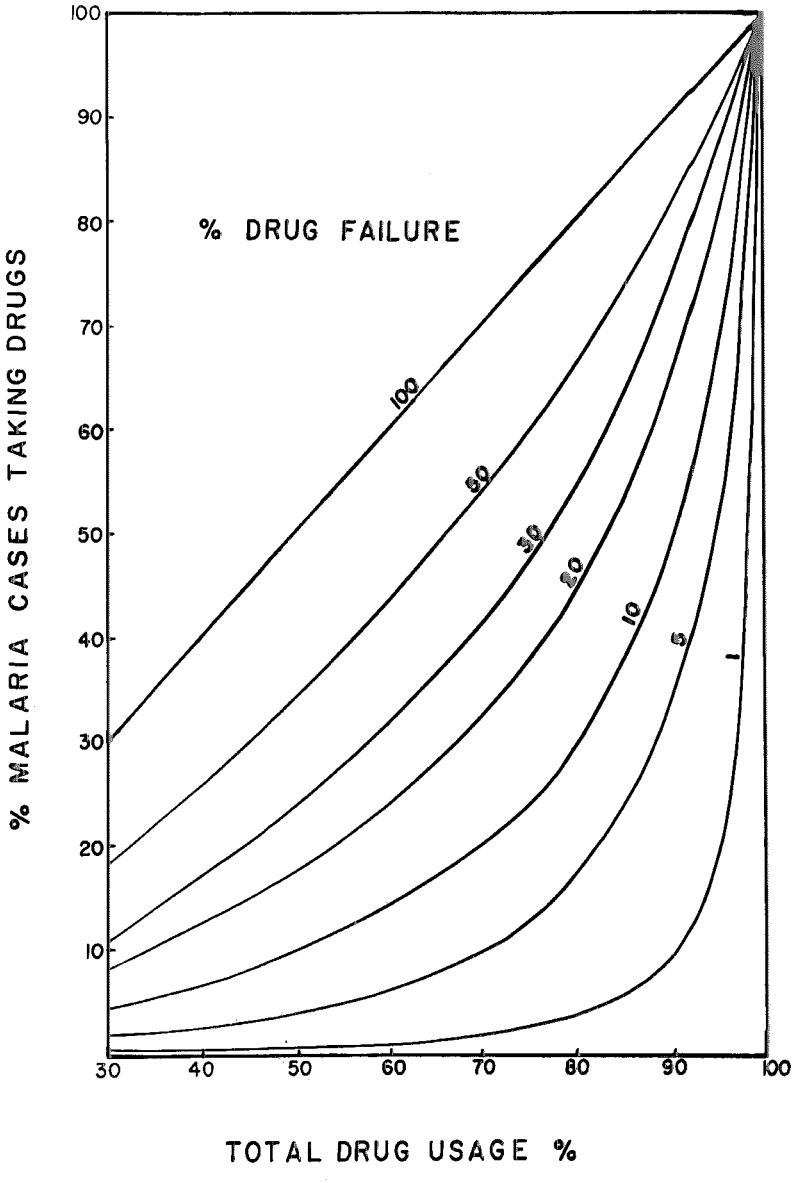

FIG. 2.—Relationship between total drug use, malaria cases which have taken drugs adequately, and drug failure rates.

Measurements of these parameters in the field are either lacking or of questionable accuracy. Nevertheless, by application of a range of hypothetical values to the model it is possible to gain a better understanding of the factors affecting malaria prophylaxis. Most available information on drug use is based on questioning of malaria patients as to whether or not they have taken the prescribed pills regularly. During 1969 a test for presence of chloroquin in the urine was introduced which is reportedly an effective index of C-P usage.

Questioning malaria patients of the 1st Marine Division during 6 months of 1968 indicated that 53 percent had taken the C-P pills regularly for the 4 weeks prior to admission (Scholdt, mimeo-report 1968). The corresponding figure for non-malaria patients was 69 percent. Application of these figures (d=69%, m=53%) to the model gives a drug failure rate of 49 percent.

It was also found that only 20 percent of *vivax* malaria patients reported regular drug participation. Application of this figure (with a 70 percent total use estimate) to the model gives a failure rate for *vivax* of about 11 percent. If the actual patient drug participation were 15 percent the failure rate would be 7.5 percent. Most of the available information does not give this kind of breakdown for *vivax* and *falciparum* so that another source of error is introduced which tends to make the failure rate for C-P against *falciparum* appear less.

Whether the total drug use rate ever exceeds 90 percent except under experimental conditions is doubtful, and the possibility that CP failure is approaching 100 percent is not beyond consideration. Five years of continual selection could be producing a situation of this kind. Even after allowance for variance from normal distribution and sampling errors there remains substantial indication of a very high failure rate.

Data from Army units in the central highlands are of particular interest when fitted to the model. Joy *et al.* (1969a) also used the interview technique to obtain information on degree of drug participation of malaria patients in a comparison of C-P and dapsone effectiveness. Their results indicate that 99 of 110 or 90 percent of personnel in units on C-P regimen had taken pills regularly while 47 of 111 or 42 percent of men in units on dapsone claimed adequate participation. No information on total drug use was available but it is logical to expect this to be quite high because every effort was made to obtain full utilization by the two experimental groups. If total use was 90–95 percent the failure rate in the C-P placebo groups would have been 100–47 percent. The failure rate in the dapsone group would be 8–4 percent. In other words the dapsone would appear to be about 12 times as effective as the CP. This becomes significant when compared with the results of a second and entirely separate field trial by Joy *et al.* (1969b) from which it was concluded that there was a ten-fold advantage for dapsone over CP.

COMBINED EFFECT OF REPELLENTS AND CHEMOSUPPRESSIVES. *Proposition—That all men using repellents adequately are removed from possible bites and infection. The non-users of repellent will be divided into users of drugs and non-users of drugs and bites by the infective vectors present will be divided proportionally between these two groups. The number of cases among the non-users of drugs will equal the number of bites by infective vectors while the number of cases among the drug users will reflect the failure rate of the drug applied to the number of infective bites on drug users. Combined effectiveness will be a function of drug usage rate and failure rate among the men who do not use repellent. When the inoculation rate is high malaria incidence may be significant even when combined effectiveness of drugs and repellents is better than 90 percent.*

Table 4 indicates the reduction in number of potential malaria cases when levels of effectiveness of combined personal

and drug control methods range from 20–90 percent. The most significant feature revealed by this model is the malaria rate which could be expected even when combined personal protection and drug effectiveness is 90 percent. A relatively moderate MBR of 5 and infective index of 1 percent would still give an incidence of 1 case/1,000/day at 90 percent effective control. Compare this with the conclusion of Joy *et al.* (1969b) that one case per battalion combat day (=33 per 1,000/month) may be an irreducible minimum. If the MBR is 10 and the effective index is 5 percent, the incidence rate even at 90 percent effective control, would be 300/1,000/month.

The attainment of much better than 90 percent control under usual operating conditions is quite unlikely in view of military experience to date in Vietnam. From all indications the adequate use of repellents is seldom greater than 50–70 percent and at these levels little or no decrease in rates would be expected for reasons discussed above and indicated by Table 5. At 70 percent effective repellent usage there would be 700 men per 1,000 removed from any possible chance of inoculation, leaving 300 vulnerable to bites by available infective vectors. If all 300 are regular drug users the malaria rate should reflect the extent of drug failure. If we assume a failure rate of 40 percent for CP and 10 percent for dapsone and an MBR-infective index of 5–1 (10 infective vectors per day) there still would be 4 cases or 1 case/1,000/day depending on the drug used. However, it is improbable that all those who failed to use repellent would be conscientious drug users; therefore, these would be only the hypothetically lowest rates obtainable. At the other extreme, where all 300 not using repellent also fail to take drugs, there would be a potential of 10 cases/1,000/day because none would have any drug protection. This converts to a minimum of 30 cases/1,000 per month for dapsone users, 120 cases/1,000/month for C-P users and a maximum of 300/1,000/month if all of those individuals who fail to use repellents also fail to take suppressive drugs. Proportional distribution of drug users between these extremes should give a corresponding distribution of the 10 infective vectors per day between drug users and non-drug users.

DISCUSSION

The hypothetical model is based upon fixed relationship but most of the actual values used are merely assumptions. A change in any one value results in a corresponding change in other values. Therefore, the deduction of failure rates for CP and dapsone cannot be construed as a demonstration of the validity of the calculated values until "d" and "m" are measured with some degree of accuracy. Field trial comparisons are also subject to criticism because they start from a basic assumption that the experimental groups are exposed to infective vectors in an approximately equal degree. Army and Marine units in the Au Shau and Ken Valleys exhibited a 70-fold difference in malaria rates for a brief period during 1969. Some observers have suggested that this may have been due to differences in malaria discipline because surveys indicated an 80–90 percent repellent and drug utilization rate for Army units and 60–70 percent for Marine units. It was assumed that exposure was about the same because of the similarity of topography and proximity of locations. It is most unlikely that these relatively small differences in malaria discipline could account for such a great disparity in malaria incidence.

These considerations do not mean necessarily that the field evidence in favor of dapsone is invalid. It could be argued with equal logic that the results of field trials plus the evidence from controlled studies with volunteers support the conclusion that the degree of exposure of the experimental groups was in fact similar. However, differences in the MBR and infective index product could account for

the considerable controversy among medical officers as to the effectiveness of dapsone. The conclusion of many that it has been of no value relative to C-P may be based on experience with units on dapsone which had been operating in an area with an inoculation potential of 100/1,000/day or more (Table 4). In this case 90 percent effectiveness would still result in 10 cases/1,000/day or 300/1,000/month, which could hardly generate confidence in the performance of the drug.

Even if a drug with 100 percent effectiveness were available there would remain the problem of obtaining that last 5–10 percent utilization without which rates of 300 or higher per thousand per month could still occur when the vectorial capacity is high. It would seem that attempts to increase the effectiveness of personal control measures will soon, if they have not already, reach a point of diminishing returns. On the other hand, measures which provided even 50 percent reduction in vector density would reduce the malaria rate by an additional 50 percent.

Table 4 indicates how relatively small changes in vector density and infective index can produce a very large increase in malaria inoculations per 1,000/day. An MBR of 2 with an infective index of 0.5 percent will give 2 potential inoculations while an MBR of 10 and infective index of 10 percent increases this figure 100 times. A number of observations support the theory that changes in vectorial potential of this magnitude do occur (Tables 1 and 2). It is well known to mosquito workers that many natural factors can influence mosquito abundance within short distances. Proximity of breeding sources, available harborages, and flight range often account for large variations in vector density.

The infective index is even more subject to rapid changes both in respect to space and time. First of all is the requirement for presence of a host with a parasitemic condition adequate to infect the vectors. Then there is the infective life of the mosquito which depends upon daily survival rate and the sporogonic period of the malaria parasite. Garett-Jones and Shidrawi (1969) estimate the infective life of *A. gambiae* in Northern Nigeria at about 7 days when the mean interval from infection of the vector with *P. falciparum* is 12 days. Assuming that approximately similar values hold true for vectors in Vietnam the infective index should drop to zero very rapidly if there were no source of infection for newly emerging vectors. This must be the case frequently when malaria-free units enter a new area and drive out the enemy or local population. The unit might be exposed to a high vectorial capacity initially and yet experience a rapidly decreasing rate of inoculation within a few days as infective vectors die off.

This could have been the situation at Ken Valley where there were 53 cases/1,000/day over a 5-day exposure period (Table 3). If this unit had remained for 30 days there might have been no additional inoculations and the *rate* reduced to 9/1,000/day. On the other hand, the unit at Lang Vie was garrisoned adjacent to a Montagnard village where a continuous source for infection of vectors was available and an increasing vectorial capacity might be expected. The unit at BaLong remained for several months and provided its own parasite reservoir.

Malaria in Vietnam during military operations is characterized by extreme variation in endemicity both in respect to time and space. A few hundred yards or a few days may be far more significant than the most effective of control measures in determining malaria rates. A typical example was seen at Phu Bai in July 1965. Four cases of malaria occurred within a few days in "C" Company of the 3rd Motor Transport Battalion based at the perimeter of the airfield. There had been no cases among the remainder of several thousand men living within a mile of the airfield, *except* among those who had been

on patrols or outpost duty in the foothills several miles to the west. Investigation revealed that the malaria cases in "C" Company had not been outside the area but had been sleeping within 50 feet of several Vietnamese refugee families who had taken over a group of rooms in an old hangar.

What should be the basis for the malaria rate attributed to these 4 cases? The 8 or 10 men living in the hangar? The total number in "C" Company? Or the total population at the Phu Bai base camp? The rate per 1,000 per month could vary from less than 5 to 2,000 or more depending on the base population selected, as well as the time period. Actually the population at risk was most probably restricted to the few personnel sleeping in the immediate vicinity of perhaps only one human host and a few infective vectors.

Until recently there had been no evidence that malaria cases have originated in significant numbers at the Phu Bai base camp even though many parasite reservoirs must have returned there with considerable frequency from hyperendemic areas. This situation would be expected in the absence of an efficient vector. However, recent reports of increased malaria incidence in areas such as Phu Bai could be explained even with an inefficient but common vector if the parasite reservoir is high. An MBR for *A. sinensis* of 20 with an infective index as low as .05 percent could produce 2 inoculations per 1,000 per night or 60 per month. At 90 percent effective drug control this would still give 6 cases/1,000, which in a population of 5,000 is 30 cases per month.

In the absence of accurate measurements, study of these model relationships will not provide valid answers to the many unanswered questions. However, they should be useful in providing a better understanding of the significance of the unknowns and may stimulate efforts to obtain more dependable information by surveys of both the human subjects and the vectors.

SUMMARY

Man-biting rates for vectors obtained at several locations in Vietnam and assumed infective indices are used to construct a hypothetical model which indicates potential malaria inoculations per thousand per day. Application of information on use of repellents and drugs, and on malaria incidence from limited areas to the model provides a better understanding of the relative value of personal control measures. Adequate use of repellent protects the individual user but has little effect in reducing malaria incidence *rates* unless the total usage exceeds 90 percent. A model is also demonstrated for the relationship between total drug use, percent of malaria patients with adequate drug participation, and the drug failure rate. Accurate field data on all of these factors have not been available but application of probable ranges of values suggests failure rates of 40–100 percent for chloroquin-primaquin against *falciparum*, 5–15 percent against *vivax*, and 4–10 percent for dapsone against *falciparum*. Significant effectiveness of personal protective measures requires a very high use rate of repellents and suppressive drugs and a low drug failure rate. It is unlikely that overall reduction in case incidence by repellents and drugs from total potential malaria inoculations will often exceed 90 percent. In hyperendemic localities where the man-biting rate might be 10 per man per night and the infective index 5 percent, the potential inoculation rate would be 100/1,000/day. Even if personal control measures were 90 percent effective this would still produce a potential case rate of 10/1,000/day or 300/1,000 per month. Do we need more research on vector control methods?

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laria and sniper attacks in order to obtain the basic data on man-biting rates.

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CALIFORNIA ENCEPHALITIS VIRUS ISOLATION FROM BRITISH COLUMBIA MOSQUITOES

DONALD M. McLEAN, M.D.

Department of Microbiology, University of British Columbia, Vancouver 8, B.C., Canada.

During the summer of 1969, field investigations of the ecology of tick-borne Powassan (POW) virus, mosquito-borne St. Louis encephalitis (SLE) virus and California encephalitis (CE) virus were undertaken in the South Okanagan District of British Columbia around Penticton (119°30′ W, 49°30′ N). These investigations were stimulated by: (1) the detection of POW antibodies in columbian ground squirrels (*Citellus columbianus*), and CE antibodies in both snowshoe hares (*Lepus americanus*) and columbian squirrels during a preliminary serologic survey in 1967 (McLean *et al.*, 1968); (2) detection of CE neutralizing antibodies in 93 percent of snowshoe hares near Kamloops, B.C. by Newhouse and Gregson (1963); (3) demonstration of POW and CE antibodies in 1 to 3 percent of human residents of southeastern British Columbia (Kettyls and McLean, 1969) including one CE antibody conversion between 1968 and 1969.

Between April and August 1969, antibodies to group B arboviruses (POW, SLE) were detected in sera from 133 of 833 wild rodents by hemagglutination inhibition (HI) tests and 43 by neutralization tests. The major mammalian species collected, *Marmota flaviventris,* showed 94 of 422 with group B HI antibodies, but 7 of 60 *C. columbianus* also showed group B reactions. *Dermacentor andersoni* ticks were removed from 25 marmots, average 2.5 per animal (range 1 to 7), but no virus was isolated by intracerebral injection of suckling mice. No virus was isolated from nine tick pools collected by dragging between 11 April and 18 June.

Mosquitoes were collected by hand in shaded habitats at six collection sites between 8th June and 4th August. Of a total of 26 pools containing approximately 50 mosquitoes each, 16 pools were collected at the Grey Sage ranch (119°30′ W, 49° 15′ N). Principal species collected were *Aedes vexans* and *Aedes canadensis,* but no *Culex tarsalis* were collected.

An agent which induced encephalitis which terminated fatally 4 days after intracerebral injection of suckling mice aged