A COMPARISON OF SAMPLING METHODS FOR ADULT MOSQUITO POPULATIONS IN CENTRAL ALBERTA, CANADA

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Nine sampling methods for adult mosquitoes were compared: Malaise traps, Malaise traps baited with carbon dioxide, light traps, visual attraction trap, rotary sweep net, animal bait, human bait and captures of resting mosquitoes in a trailer. The position of the trap as well as its type was found to affect both the size and composition of the catch. Rotary sweep nets were found to have a definite attraction for mosquitoes and this may be selective for some species. Light traps caught a relatively larger proportion of parous mosquitoes than other methods, but other physiological stages showed no differences between methods.

In recent years a vast literature on sampling methods for mosquito populations has accumulated but this deals mainly with size and species composition of the catches.

In any study of trapping methods for insects it must be realized that the catch depends on three sets of factors: those in the trap, those in the environment and those in the insect.

The catch depends on the population density of the insect, its "availability" and its activity. Corbet (1961) considered that light traps in Uganda sampled only those mosquitoes engaged in non-specific activities and did not catch those engaged in feeding, swarming, or oviposition. Biddlingmayer (1967) has published a study of the effects of environment and species composition on different trap types but has not considered the effects of the physiological state of the mosquito.

Apart from Corbet (1961) I know of only one study relating the physiological state of an insect of medical importance to survey methods, the work of Bursell (1961). Barr (1958) mentions that the age and physiological state of mosquitoes affects the captures in light traps, but the citation he gives for this, Nielsen and Nielsen (1953), is incorrect, as this paper makes no mention of factors affecting light trap captures. Russian workers have paid considerable attention to the physiological age of mosquitoes, have elucidated many factors in the biology of the insects and have provided methods for determining age (Detinova, 1962) but have not related age to sampling procedure. I have attempted to fill part of this need in relation to woodland mosquitoes in central Alberta.

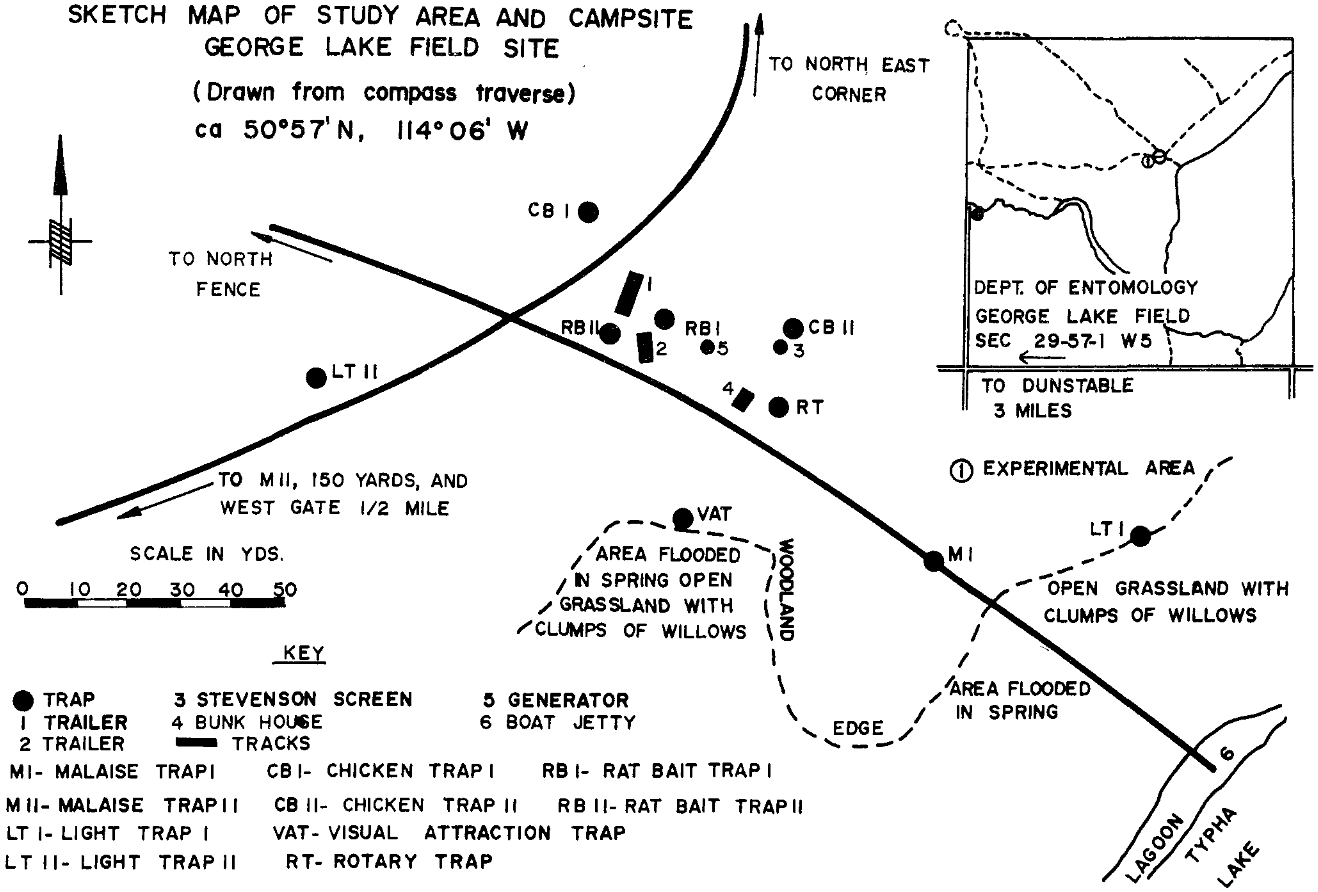
THE STUDY AREA

The study area is on the west shore of George Lake, 53°57'N and 114°06'W, about 40 miles northwest of Edmonton, Alberta. The area lies at the southern margin of the boreal mixed forest subzone (LaRoi, 1968). All traps were within 300 yards of the campsite, more or less in the centre of a square mile field site operated by the Department of Entomology, University of Alberta, (Fig. 1).

FIGURE I

SKETCH MAP OF STUDY AREA AND CAMPSITE
GEORGE LAKE FIELD SITE

(Drawn from compass traverse)
ca 50°57' N, 114°06' W



Away from the lake shore the vegetation of the field site consists of almost untouched mature poplar forest, with small areas of spruce on the northern and western boundaries. Prior to 1930 some trees were removed by neighbouring farmers, but otherwise the forest has not been disturbed. The principal trees are *Populus tremuloides* Michx. and *P. balsamifera* L.. Other trees are *Picea glauca* (Moench.), *Betula papyrifera* Marsh., *Alnus tenuifolia* Nutt. and *Salix* species. *Larix laricina* Koch. is common in neighbouring wetlands but rare on the field site. The understory is more diverse, consisting of a large number of shrub and herb species: *Amelanchier alnifolia* Nutt., *Viburnum edule* (Michx.), *Rosa acicularis* Lindl., *Cornus stolonifera* Michx. and *Ribes lacustre* (Pers.) are common shrubs. *Cornus canadensis* L., *Solidago* species, *Epilobium angustifolium* L., and *Aster* species are common herbs. *Ledum groenlandicum* Oeder. forms more or less oval bogs in a few places, usually on clumps of sphagnum moss. On the northern boundary there is an area of sedge (*Carex* species) meadow which contains a number of permanent water holes. A stream flows out of the lake just south of the campsite and is blocked by several beaver dams. There is a fringe of *Carex* bordering the lake and a floating mat of *Typha* species round the lake edge.

About half the surrounding country is cleared for cultivation and grazing, mainly on the east, south and northwest, resulting in a patchwork of woodland, pasture and cultivation which allows a rich mosquito fauna (Graham in prep.).

In the winter of 1964-1965 above normal snow falls were recorded and melt water remained well into summer. Also nearly six inches of rain fell in the last two weeks of June 1965. Thus the majority of spring larvae were able to complete their development and second broods of many species developed. In the winter of 1965-1966, below normal snow falls occurred and most melt water had dried up by late spring, so many larvae did not complete development. Heavy rains did not fall till late July and August and the resulting pools soon dried up, so second broods were not prominent. Heavy snow fell in the winter of 1966-1967, but did not melt till the end of April. In 1966, snow had almost disappeared by 21 April, but in 1967 it was still deep on this date. Break up of ice on the lake had occurred on 21 April 1966 but did not take place till the end of the first week of May in 1967. According to Mr. E. Donald, a neighbouring farmer, the 1967 spring was ten days to two weeks behind the long term average at George Lake. Table 1 presents names of the major species of mosquitoes taken and their abundance in 1966.

An example of the difference in mosquito populations in the 1965 and 1966 seasons is given by the captures in a light trap operated at the Victoria Golf Course in the City of Edmonton. In 1965 this trap was run from 9 July to 30 August and caught 2826 mosquitoes, an average of 75 per night. In 1966 the same trap was run from early May to the end of August and caught six mosquitoes. Control measures in the urban area were the same in both years. In the spring of 1967 traps at George Lake caught approximately four times as many mosquitoes as in the spring of 1966, though I had the impression that the mosquito nuisance in the field site was worse in 1966.

METHODS

Sampling

Nine methods of sampling adult mosquitoes – Malaise traps, New Jersey light traps, a

Table 1 Numbers of mosquito species identified at George Lake in the spring and in summer of 1966.

Species	Number Identified	% of total Identified
Anopheles earlei	41	1.8
Culiseta inornata	187	8.4
Other *Culiseta*	63	2.8
Culex territans	43	1.9
Mansonia perturbans	36	1.6
Aedes cinereus	62	2.8
A. communis	75	3.3
A. excrucians	518	23.3
A. fitchii	199	8.9
A. implicatus	47	2.1
A. punctor	188	8.4
A. riparius	80	3.6
A. vexans	517	23.3
Other *Aedes*	186	8.4
Total *Aedes*	1871	83.5
Total caught	2459	
Number of species	28	

visual attraction trap, a rotary sweep net, chicken bait, rat bait, human bait, carbon dioxide bait, and collections of resting mosquitoes inside a trailer – were tested in this study. The localities of these traps are shown in Fig. 1. Traps used in different years were operated in the same places.

All meteorological data were obtained from a recording thermohygrograph in a Stevenson screen at the campsite.

Malaise traps. – This type of trap was first described by Malaise (1937), but its importance in ecological studies has only recently become apparent. I chose the modification of Townes (1962) as it is operational from all four directions. Breeland and Pickard (1965) and Smith *et al.* (1965) have recently demonstrated the value of this type in mosquito studies.

One trap was used in 1965 and two in 1966 and 1967. These had four entrances four feet high and six feet wide and the catching head was eight feet above the ground. The traps were erected over old tracks, MI near the lake shore and MII on the top of a low rise about 300 yards into the forest. Calcium cyanide, in the form of Cyanogas G, was used as a killing agent. Three teaspoonfuls in a manila envelope remained lethal for five days. The traps are shown in Plates 1, 2 and 3.

Light traps. – Two battery-operated standard New Jersey light traps (Lt) were used. This type was chosen as it is perhaps the trap most frequently used by mosquito workers. I decided not to use ultra violet light since the standard model is more often used and some studies (Zhogolev 1959; Downey 1962) have indicated that while U. V. greatly increases the catch

Plate 1 Malaise trap I as seen from the bunk house.

Plate 2 Malaise trap II in April 1967.

of some biting flies it might be less attractive to some mosquito species. It was not possible to compare U. V. with the standard model.

One of the two, Lt I, was situated at the forest edge on the lake shore and the other, Lt II, a short distance into the forest. A six volt car battery operated one of these traps for three nights. Air flowed at 121.5 cubic feet per minute through Lt I and at 120 cubic feet per minute through Lt II. These figures were determined with a Biram's anemometer. The light traps are shown in Plates 4, 5 and 6.

Visual attraction trap. – A visual attraction trap of the type described by Haufe and Burgess (1960) was used, with a net, instead of the hourly timing device described, for collecting the catch (Plate 7). Unfortunately, only one trap was available and the power supply permitted only restricted hours of operation.

The cylinder made one complete revolution every two seconds and the air flowed through the trap at 741 cubic feet per minute. Complete engineering blue prints of this trap are obtainable from the Canada Department of Agriculture, Medical and Veterinary Entomology Branch, Lethbridge, Alberta.

This type of trap was originally developed for use in the north, where short summer nights make light traps inefficient.

Rotary sweep net. – A group of four electrically driven rotary sweep nets was used. Two nets were at 45.5 inches and two at 58 inches above the ground. At each level, the base of one was 23 inches and the other was 34 inches from the shaft, so that no two nets swept the same volume of air. The nets were 12.5 inches in diameter and the trap made one complete revolution per second, thus the trap swept 1167 cubic feet of air per minute (Plate 8). The insects caught were removed with an aspirator. Operation of this trap was restricted by the power supply.

Rotary traps have been used by several workers (Chamberlin and Lawson, 1945; Stage and Chamberlin, 1945; Stage *et al.*, 1952; Love and Smith, 1957) who assumed the traps have no attraction for insects and take unbiased random samples.

Chicken baited traps. – Two small traps were constructed in 1965; each held one chicken. These were not very successful.

Two large traps each capable of holding several birds were used in 1966. They were six feet long, by four feet wide, 12 inches high at the corners and 22 inches high at the centre. One end was closed in with a roosting box 17 inches by four feet in dimension. The floor was one inch mesh wire cloth. Four egress traps protruded from the roosting box, two on each side. The rest of the sides were made of 14 x 18 inch mesh galvanized wire gauze. Ingress traps were tried but the birds sat on them and broke them. The mosquitoes entered by the wire cloth floor and were caught in the egress traps as they left. The traps did not catch many mosquitoes, possibly because the birds ate them.

The two traps were designated CBI and CBII (Plates 9 and 10). CBI was baited with white leghorns and CBII with bantams. The latter often escaped so that the number in the trap varied from two to five. These traps were only operated in 1966.

Rat baited traps. – The two traps used with chickens in 1965 were modified and used with rats in 1966. Each was of a different design. They were designated RBI and RBII. RBI was a modified Magoon (1935) trap 19 inches long and 17 inches wide and 12 inches high. The animal chamber was closed in by 14 x 18 inch mesh galvanized wire gauze so that

Plate 3 Catching head of Malaise trap I.

Plate 4 Light trap I as seen from the Lake shore.

Plate 5 Light trap I showing proximity to the Lake.

Plate 6 Light trap II showing position in the forest.

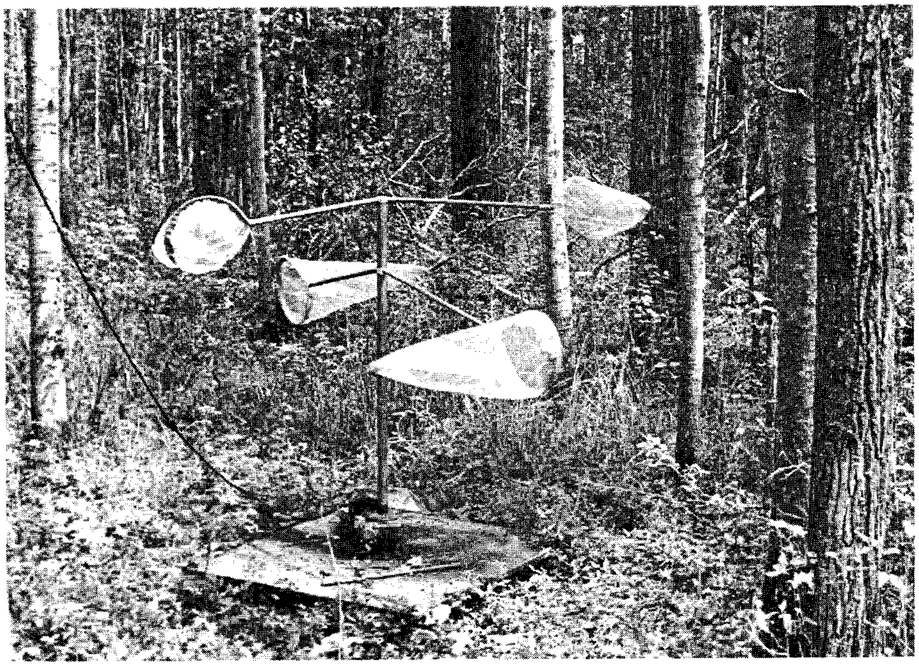


Plate 7 The visual attraction trap.

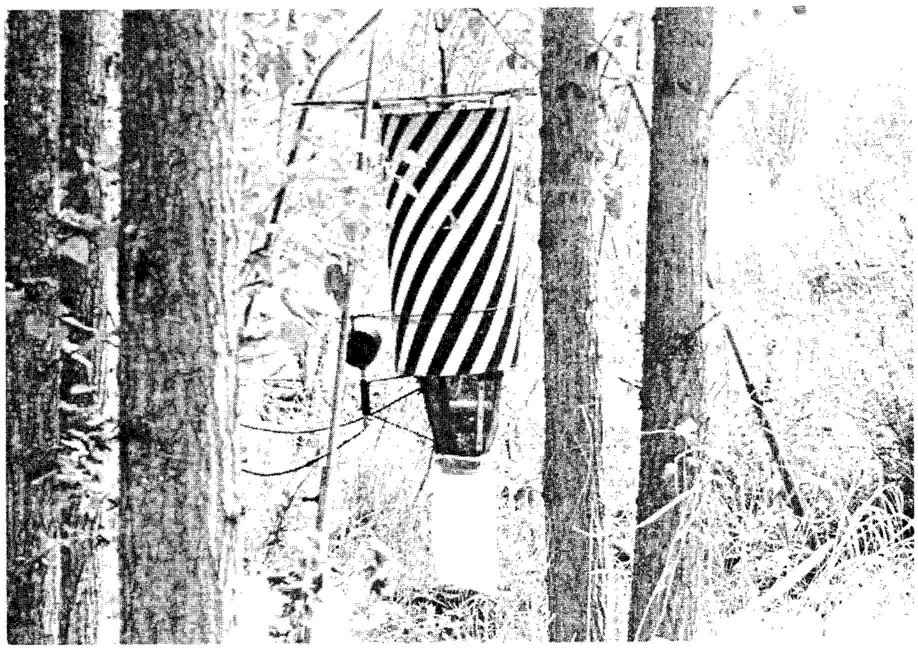


Plate 8 The Rotary trap.

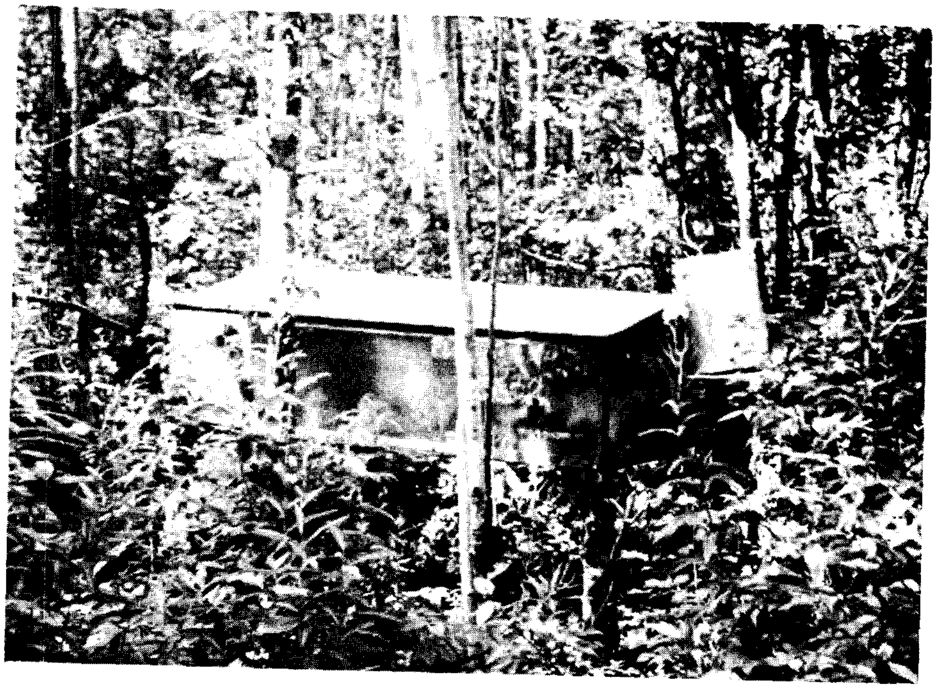


Plate 9 Chicken baited trap I.

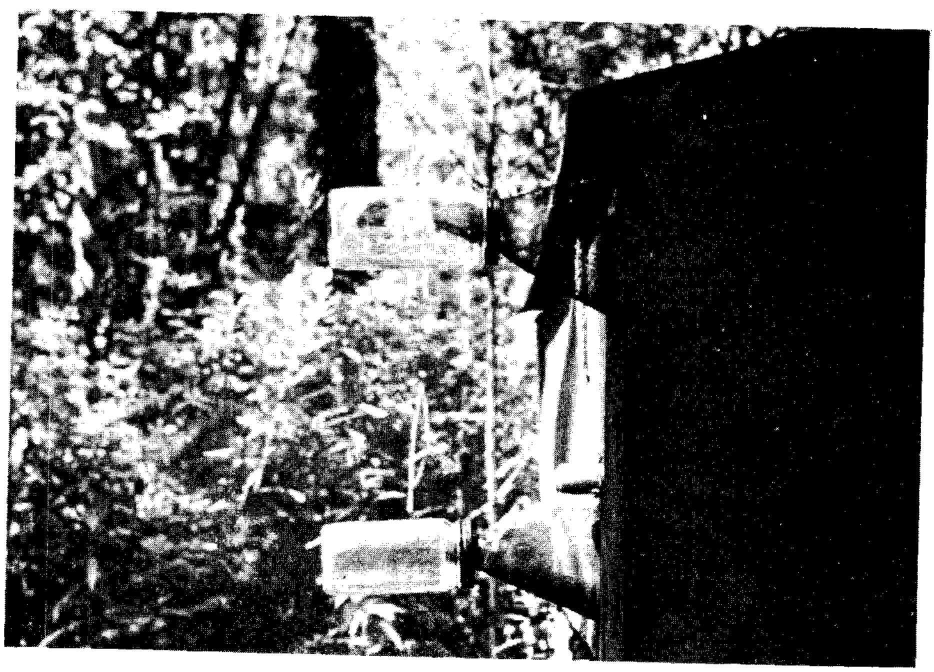


Plate 10 The catching cages of chicken baited trap II.

the mosquitoes could not reach the bait. The mosquitoes entered a collecting cage 19 inches long, six inches high and six inches wide by means of a no-return baffle and were removed with an aspirator. RBII was a circular trap, 15 inches in diameter with the bait cage coming to a cone 12 inches high. This cone projected through a hole three inches in diameter in the top plate into a cone three inches high in the bottom collecting cage, the two forming a no-return baffle. The catching cage was a removable cylinder nine inches high and 10 inches in diameter. Flanges six inches wide in RBI and 4½ inches wide in RBII were added in 1966 to direct the mosquitoes into the trap. These traps are shown in Plates 11 and 12.

Originally three rats were used in each cage, but births often modified this. These two traps were run close to each other in the middle of the campsite. RBI was operated in June, July and August 1966 and May and June 1967; RBII was only operated in July and August of 1966.

Many designs have been suggested for animal bait traps using large animals, the so-called stable traps of Magoon (1935), Bates (1944), Roberts (1965), but relatively little attention has been given to the use of small animals as mosquito bait (Southwood, 1966). These would appear to offer certain advantages because of their smaller size and the fact that they need less attention than cattle or horses.

Human bait. – On one day in most weeks from late May to the end of August, 1966, I sat quietly with trouser legs rolled up and caught any mosquitoes which alighted in a fifteen minute period. In May these collections were made in the afternoon and after that at 1800 hours.

Carbon dioxide baited traps. – Several authors (Brown, 1951; Bellamy and Reeves, 1952; Newhouse *et al.*, 1966 and others) have shown that carbon dioxide used alone or in conjunction with another attractant is good bait for mosquitoes. I decided to try the release of carbon dioxide from a cylinder in Malaise traps. The gas was released at from one to six litres per minute with an average rate of five litres per minute (approximately equivalent to the amount of carbon dioxide expired by 20 men at rest). It proved difficult to control the flow accurately in the field with changing conditions of temperature and barometric pressure. The gas was released through a flowmeter and led up into the catching head by means of a plastic tube (Plate 13). On the night of 12/13 July, 1966 releasing the gas direct from the cylinder without a flowmeter was tried. Both 25 lb. and 50 lb. cylinders of carbon dioxide were tried; the former proved better as they were more portable. One 25 lb. cylinder lasted approximately 16 hours. The traps were run from 1700 hours to 0900 hours the following morning.

Carbon dioxide was used on alternate nights, the other Malaise trap being used as a control. Carbon dioxide traps were operated in July and August 1966 and May and June 1967.

Collections of resting mosquitoes and miscellaneous collections. – Also on one day per week in June, July and August, 1966 and from 16 May to 15 June 1967, all mosquitoes found resting in one of the trailers at the camp were collected early in the afternoon. In June 1966 this trailer was used as a kitchen and dining room, thereafter as a store. In 1966 a carton of dry ice was kept in it and rats were kept there over weekends in a screened cage. In 1967 rats were kept in the trailer in a unscreened cage.

Plate 11 Rat baited trap I.

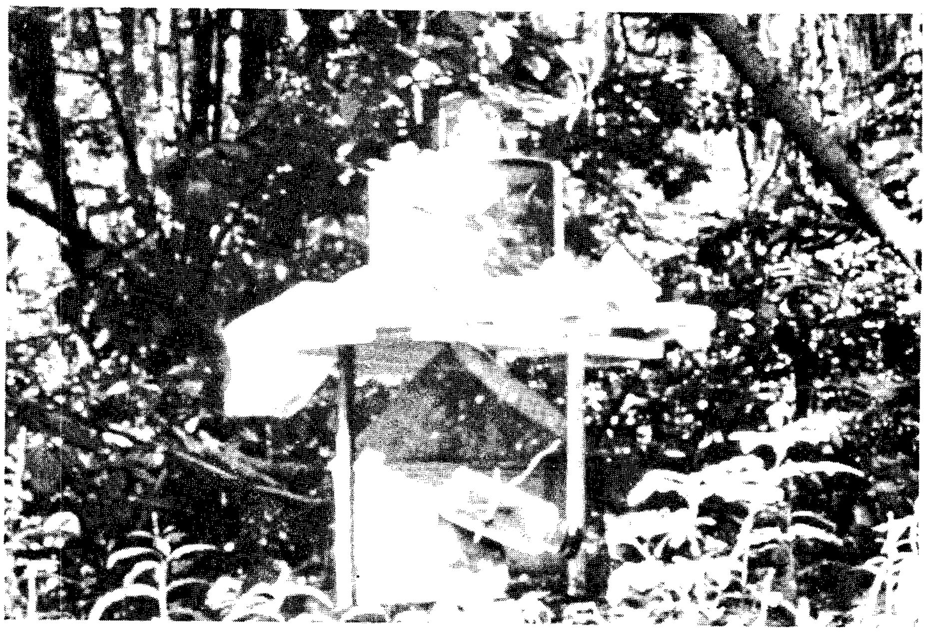


Plate 12 Rat baited trap II.

Plate 13 Malaise trap I with CO_2 cylinder in place.

At various times during the summer of 1966, mosquitoes were caught with a sweep net, when biting at times other than when human bait captures were in progress and in a C. D. C. (Communicable Diseases Center) miniature light trap. These collections have been included only in total catch figures.

Handling and Dissection

Weekend catches of Malaise traps, human bait, and miscellaneous collections were identified and counted. All other collections were frozen and taken to the laboratory. There they were identified, counted and dissected or, if numerous, subsampled and dissected. In 1967 the very large collections in carbon dioxide traps were subsampled for dissection and subsampled again for identification. The number of specimens in each sample was estimated from these two subsamples. This estimated number was used to obtain the proportion of each species in the total carbon dioxide trap catch. The number identified varied from 100% to 20% of the total, being proportionately smaller in the larger samples. This is probably an accurate estimate of the numbers of the more numerous species but not of the rarer ones.

Specimens for dissection were first assigned to a stage of Sella (Detinova, 1962) and to one of five arbitrary categories of external wear. They were dissected in distilled water under X12 of a Wild M5 stereomicroscope. The contents of the ventral oesophageal diverticulum and the mid gut were noted. The ovaries were then examined under X50 for the stage of Christophers (Clement, 1963).

The ovaries were removed to a drop of water on a microscope slide, allowed to dry and stored till they could be examined for parity or nulliparity by Detinova's method of ovarian tracheation (Detinova, 1962). The ovaries were then examined in a drop of distilled water under X100 of a Propper compound microscope.

All dissections were done within one week of capture and the specimens were kept frozen in dry ice until dissected. Corbet (1961) showed that mosquitoes were suitable for dissection after being kept frozen for three months. I found that it was possible to use Detinova's method on ovaries which had been stored dry on a slide for a year.

Males were counted and identified to genus only.

Except for Malaise trap captures all mosquitoes were killed by freezing with dry ice.

RESULTS AND DISCUSSION

Malaise traps, light traps, visual attraction trap, rotary trap, rat bait, chicken bait and Malaise and carbon dioxide were compared both quantitatively and qualitatively. Two methods – human bait and collections in the trailer – were not standardized enough for quantitative comparison.

Note on statistics used

The statistical analysis of the data obtained in this study presented certain difficulties, since the nature of the study did not allow the randomization of catches. All traps had to be operated in the same place and technical difficulties as well as the nature of some of the traps prevented simultaneous operation. Therefore the statistical tests applied are not all strictly applicable to the data obtained, though I believe they assist in the interpretation of the results.

Quantitative comparison of the trap types was obtained by converting the catch into catch per 100 trap hours to standardize and to allow for the fact that the different traps were run for different lengths of time. This test is not strictly applicable but does help to confirm conclusions reached by other methods. An index of trap "effectiveness" was obtained by dividing the catch per 100 trap hours in the trap or trap type under consideration by the catch per 100 trap hours in the combined Malaise traps over the same period. The Malaise traps were chosen as standards as they appear to be passive and to have no attraction for mosquitoes. The combined Malaise traps were used in an attempt to minimize the effects of trap position. This "index of effectiveness" permits a ranking of traps and trap types in order of effectiveness.

A modified geometric mean, the Williams mean (Haddow, 1960), was used for studying the effects of the addition of carbon dioxide to Malaise traps. It is obtained by the expression $M_W = \text{antilog}\left[\frac{(\Sigma \log(x+1))}{N}\right] - 1$ where x is the value of each sample and N is the number of samples. The addition of one to each sample value allows the inclusion of zero catches which cannot be included in a normal geometric mean. Williams has shown that where there is a large variation in the size of samples or one sample is very different from the others, this mean gives a better measure of central tendency than the arithmetic mean.

The χ^2 test was used in the qualitative comparison of the trap types. Simpson *et al.* (1960) was the principal reference used for statistical methods.

Relative effectiveness – catch per unit time

Table 2 shows the relative effectiveness of the traps in 1966 and 1967 and Table 3, the effectiveness in June of 1966 and 1967. Table 4 shows the catch per 1000 trap hours of the five most abundant species and *Culex territans* which is believed to feed on cold blooded vertebrates and so differs from the other species caught which are believed to feed mainly on warm blooded vertebrates.

The results in May and June 1967 are similar to those in 1966 except that light traps caught less than either the visual attraction or the rotary traps and the catch per 100 trap hours in all traps averaged four times larger than in 1966.

Perhaps the most interesting result was the high catch in the rotary trap which is generally believed to have no attractive influence and to take a random sample of flying insects (Stage and Chamberlin, 1945; Love and Smith, 1957; Juillet, 1963; Southwood, 1966). This trap had an index of effectiveness of 5.1 in 1966 and 9.7 in 1967 and was well within the range of traps with an attractive influence, namely light, bait, and visual attraction traps. This indicates that the rotary trap does in fact exert some attractive influence on mosquitoes. It was impossible to observe the approach of mosquitoes to a trap of this size so that the nature of this influence could not be elucidated. It is well known that many biting Diptera including mosquitoes (Clement, 1963) are attracted to moving objects. Tabanids and tsetse flies (*Glossina* sp.) are attracted to moving motor vehicles (Duke, 1955; Glascow, 1963). The stimulus of a rotary trap may be similar to that of a moving vehicle.

Though the light traps caught nearly three times as many mosquitoes in June 1967 as in June 1966, their relative effectiveness was nearly halved. This is probably due to the absence of *Culiseta inornata* in 1967 as this species formed a large proportion of the 1966 catch.

Table 2 The numbers of adult female mosquitoes taken per 100 trap hours in different traps at George Lake 1966 and 1967.

Trap	No. Caught	No. trap hours	No. mosq/ 100 hours	Index of *** Effectiveness
	1966 (June July August)			
Malaise I	146	2099.5	7.0	0.8
Malaise II	214	2048	10.7	1.2
Total Malaise	365	4147	8.8	1.0
Mal I+CO_2*	589	104.5	559.4	67.6
Mal II+CO_2*	264	98	269.9	30.7
Total Mal+CO_2*	853	207.5	411.1	51.1 (35.1)** *
Light I	141	266.5	52.9	6.0
Light II	48	267	18.0	2.0
Total Light	184	533.5	35.4	4.0
Vis. attr.	93	261.2	35.6	4.0
Rotary	116	260	44.6	5.1
Rat baited I	154	711.5	21.6	2.5
Rat baited II*	19	191	9.9	1.1
Total rat baited	172	902.5	19.1	2.2
Chick. baited I*	42	744	5.6	0.6
	1967 (May June)			
Malaise I	124	977	12.7	0.53
Malaise II	344	977	35.3	1.47
Total Malaise	468	1954	24.0	1.0
Mal I+CO_2	1080	112	964.2	40.26
Mal II+CO_2	5640	112	5035.7	210.2
Total Mal+CO_2	6720	224	3000.0	125.3 (97.4)** *
Light I	93	120	77.5	3.4
Light II	37	120	30.8	1.3
Total Light	130	240	54.2	2.3
Vis. attr.	56	49	114.3	4.8
Rotary	114	49	232.6	9.7
Rat baited I	129	262	49.2	2.1
Rat baited II	–	–	–	–
Chick. baited I	–	–	–	–

* August only.

** Adjusted using Malaise trap figures per equivalent nights.

*** The 'Index of Effectiveness' is the no. of mosquitoes per 100 trap hours taken in trap, divided by the no. of mosquitoes per 100 trap hours in the combined Malaise traps.

Table 3 Comparison of mosquito captures per 100 trap hours in June 1966 and June 1967 at George Lake.

Trap	1966	1967	Index of Effectiveness 1966	Index of Effectiveness 1967	Comparative Increase in catch 1966/67
Malaise I	5.14 (37)	16.8 (108)	0.76	0.49	3.26
Malaise II	9.45 (59)	51.3 (329)	1.32	1.50	5.43
Total Malaise	7.13 (96)	34.1 (437)	1.0	1.0	4.78
Light I	45.83 (44)	135.9 (87)	6.40	3.98	2.96
Light II	15.0 (12)	51.6 (33)	2.10	1.51	3.44
Total Light	35.0 (56)	93.8 (120)	4.91	2.75	2.68
Vis. attr.	41.30 (46)	137.5 (55)	5.79	4.03	3.32
Rotary	31.40 (36)	285.0 (114)	4.40	8.36	9.08
Rat baited I	25.4 (97)	79.2 (122)	3.56	2.32	3.12

Fig. in brackets = no. mosquito caught. Av. increase 4.30

Apart from the rotary and light traps the "indices of effectiveness" for the two years are very similar. This indicates that the relative effectiveness of a trap does not change much with population size; but it may be changed considerably if the species composition changes.

The number of mosquitoes per unit volume of air filtered in June 1967 was calculated for the rotary, visual attraction, and light traps. Only the volume of air flowing through the trap was used; no estimate of "area of influence" was made. This gives an estimate of the actual efficiency of these traps. The rotary trap captured 2.4 mosquitoes, the visual attraction trap 0.3 and the light traps 1.3 mosquitoes per 10,000 cubic feet of air. If it is assumed that rotary traps have no attraction to mosquitoes but capture only those which come within range, then the efficiency of rotary and Malaise traps should be approximately the same. I calculated the air flow needed to give a catch of 34.1 mosquitoes per 100 trap hours (the figure in Malaise traps) if the efficiency in Malaise traps is the same as that of the rotary trap. This was 23.5 cubic feet per minute, which means that the average wind speed through these traps would have been 0.9 feet per minute. That is, these traps would have to have been standing in virtually still air during June 1967; since this was not so, I infer that the efficiency of the Malaise traps was below that of the rotary trap.

The high actual efficiency of the rotary trap, above both light and visual attraction traps, is additional evidence that this type of trap does provide an attractive stimulus for mosquitoes.

Proportion of males

Comparatively few males were taken and relatively little attention was paid to them as they formed only about 1% of the total catch in 1966 and 1967. Table 5 shows the proportion of males taken in 1966 and 1967.

Table 4 Numbers of adult females of selected species of mosquito caught per 1000 trap hours and actual numbers caught in different trap types at George Lake from 1 June to 1 September 1966.

Trap	*Culiseta inornata*	*Culex territans*	*Aedes excrucians*	*A. fitchii*	*A. punctor*	*A. vexans*
Malaise I	20 (72)	6 (20)	10 (37)	1 (3)	3 (11)	7 (23)
Malaise II	6 (18)	2 (6)	27 (89)	10 (32)	3 (11)	4 (14)
Total Malaise	13 (90)	4 (26)	19 (126)	5 (35)	3 (22)	6 (37)
Malaise I+CO_2	100 (11)	9 (1)	632 (69)	289 (36)	421 (46)	3352 (336)
Malaise II+CO_2	10 (1)	10 (1)	1165 (114)	405 (40)	112 (11)	785 (77)
Total Malaise +CO_2	58 (12)	10 (2)	1002 (183)	365 (76)	275 (57)	2135 (413)
Light I	264 (70)	8 (2)	30 (8)	49 (13)	8 (2)	23 (6)
Light II	4 (9)	0 (0)	38 (10)	8 (2)	8 (2)	22 (6)
Total Light	148 (79)	4 (2)	34 (18)	28 (15)	8 (4)	22 (12)
Visual attraction	0 (0)	38 (10)	70 (18)	27 (7)	54 (14)	8 (2)
Rotary	12 (3)	15 (4)	39 (10)	31 (8)	50 (13)	31 (8)
Rat baited I	1 (1)	0 (0)	59 (42)	21 (15)	31 (22)	7 (5)

Table 5 Proportions of male mosquitoes in traps at George Lake, 1966 and 1967.

Trap	1966 (1st June – 1st Sept.) No. ♂♂	Total catch	♂ : ♂ + ♀	1967 (15 May – 30 June) No. ♂♂	Total catch	♂ :♂ + ♀
Malaise I	12	158	0.076	9	133	0.068
Malaise II	8	228	0.035	21	365	0.058
Total Malaise	20	386	0.052	30	498	0.060
Mal I+CO_2	2	512	0.0039*	5	1085	0.00461
Mal II+CO_2	0	130	0.00*	5	5645	0.000886
Total Mal+CO_2	2	642	0.0031*	10	6730	0.00148
Light I	10	149	0.067	6	99	0.061
Light II	35	78	0.45	5	42	0.12
Total Light	45	227	0.20	11	141	0.078
Vis. attr.	13	106	0.123	2	58	0.034
Rotary	4	120	0.033	1	114	0.0088
Total	83	1480	0.00561	52	75.36	0.00069

χ^2_2 1966 – 33.033 P = 0.005 (Light against rest)

χ^2_2 1967 – 1.457 P = 0.5 (Light against rest)

* August only

In both years light traps took the largest proportion of males, but the statistical significance of this is doubtful. The position of the trap was important; Lt II took a much greater proportion in both years than Lt I. Light traps are known to take a larger proportion of the males of some insects than are in the population (Southwood, 1966) and to take large numbers of male mosquitoes (Barr, 1958). Belton and Galloway (1965) found 50% of light trap captures of nearly 6000 mosquitoes were males at Belleville in Ontario. Breeland and Pickard (1965), however, found 22% in Malaise trap captures were males but only 12% in light traps.

Species composition

Diversity. – The index of diversity α was introduced by Fisher *et al.* (1943) as a measure of the diversity of a population. It is obtained from the expression $S = \alpha \log_e(1+N/\alpha)$ where S is the number of species and N the number of individuals. An approximation, adequate for most needs, can be obtained from nomograms in Williams (1964) and Southwood (1966). This index is dependent on the size of the sample as well as its diversity but is useful for comparing traps operated the same period and has been successfully used to compare methods of catching Heteroptera by Southwood (1960).

The indices of diversity for the trap types in 1966 are shown in Table 6. There were no significant differences between trap types, which indicates that the smaller catches were due to lower effectiveness rather than to the unavailability of certain species.

Table 6 Comparison of the percentages of the more numerous mosquito species in the traps 1st June to 1st September 1966 at George Lake.

Species	Total Malaise	Total Light	Visual Attr.	Rotary	Rat baited I	Chicken Baited	Human Bait	Trailer
Anopheles earlei	1.4	9.9	8	6	–	–	–	0.9
Culiseta inornata	11.1	43.4	–	4	0.8	–	0.8	0.9
Other *Culiseta*	4.7	1.6	–	–	–	–	0.8	–
Culex territans	1.7	1.1	13	5	–	–	–	–
Mansonia perturbans	0.6	2.8	–	1	3.9	–	1.7	–
Aedes cinereus	3.0	2.2	3	1	0.8	–	14.2	–
A. communis	2.8	0.6	3	7	9.4	12	5.0	8.9
A. excrucians	34.1	9.9	24	12	33.1	42	29.2	17.8
A. fitchii	9.7	8.2	9	10	7.9	–	18.3	7.1
A. implicatus	3.9	1.1	4	6	3.2	4	4.2	2.7
A. punctor	5.8	2.2	19	16	17.3	8	5.8	29.6
A. riparius	5.8	3.8	3	6	6.3	4	4.2	0.9
A. vexans	9.2	6.6	3	10	3.9	4	5.0	1.8
Other *Aedes*	6.4	6.7	12	17	13.4	25	10.8	29.4
Total *Aedes*	82.9	40.7	79	84	94.6	100	96.7	98.3
Total no. identified	361	182	75	83	127	24	120	111
No. Species taken	24	22	15	18	18	7	17	16
Index of Diversity α	6±0.6	0.6±0.9	5±1.0	6±1.0	5±0.8	3±1.5	6±1.2	5±1.0

χ^2_{13} Mal vs. Lt. = 75.664 $P = < 0.001$

χ^2_{9} Mal. vs. Human bait = 108.127 $P = < 0.001$

χ^2_{9} Mal. vs. rotary 44.99 $P = < 0.001$

χ^2_{5} Mal. vs. Rat baited = 22.964 $P = < 0.001$

χ^2_{8} Mal. vs. Vis. attr. = 38.204 $P = < 0.001$

χ^2_{6} Mal. vs. Trailer = 95.857 $P = < 0.001$

χ^2 Human bait vs. Rat baited = 14.283 $P = < 0.05$

Proportions of different species. – The proportions of the major species in the catches of the different trap types are shown in Table 6. Table 7 shows the proportions in paired traps.

Table 7 Comparison of the proportions of mosquito species taken in paired traps 1st June – 1st September 1966 at George Lake.

Species	Mal		$Mal+CO_2$*		Light	
	I	II	I	II	I	II
Anopheles earlei	1.4	1.4	0.012	0	9.4	12
Culiseta inornata	26.7	0.5	1.7	0.4	50.3	21
Other *Culiseta*	8.2	2.3	0.5	0	2.2	–
Culex territans	1.4	1.9	0.2	0.4	1.4	–
Mansonia perturbans	0.7	0.5	2.5	0.7	2.2	5
Aedes cinereus	1.4	4.2	2.0	0.4	0.7	7
Aedes communis	0.7	4.2	0.6	0	0.7	–
A. excrucians	23.3	41.5	14.8	43.2	5.6	23
A. fitchii	2.1	14.9	5.6	15.1	4.4	5
A. implicatus	5.5	2.8	0.2	0	0.7	2
A. punctor	6.9	5.1	7.6	4.2	1.4	5
A. riparius	3.4	7.4	3.6	2.6	5.1	–
A. vexans	13.0	6.5	57.6	29.2	4.3	4
Other *Aedes*	5.5	7.0	4.7	3.8	6.5	7
Total *Aedes*	61.5	96.0	97.4	98.6	33.8	63
Total ident.	146	215	636	264	139	43
No. species taken	21	19	19	13	21	11

* July and August only

χ^2_{12} Malaise 170.65 P = < 0.001

χ^2_6 $Mal+CO_2$ 15.11 P = < 0.01

χ^2_6 Light 26.23 P = <0.005

The low catch of *Culiseta inornata* in the rotary trap and the absence of this species from the visual attraction trap in 1966 is hard to explain since this species formed 27% of the catch in the nearby Malaise I.

The animal bait traps showed great similarity. The rat and chicken bait traps did not differ significantly while the human bait and rat bait traps differed only at the 5% level. *Aedes canadensis* formed over 20% of the catches in chicken bait traps but was scarce in other traps and *A. cinereus* was most abundant in human bait catches.

Discussion. – The results of Breeland and Pickard (1965) are of interest. They found 52% of Malaise trap captures were *Aedes* compared to 54% in light traps and 50% in biting catches. Forty seven percent of the *Aedes* in their Malaise traps and 52% in their light traps were *A. vexans*, which indicates that the preponderance of this species in light traps is often more due to its preponderance in the population rather than to any specific attraction to light, though this species is often stated to be greatly attracted to light (Huffacker and Bach, 1943; Love and Smith, 1957). Although Love and Smith found a high "index of attractivity" to light for this species, the proportion of *A. vexans* was actually higher in their sweep nets than in their light traps (53% and 50% respectively). Breeland and Pickard found light traps gave a significantly lower diversity, 3±0.3, than the Malaise traps, 5±0.5 (my calculations). At George Lake only *Culiseta inornata* and *Anopheles earlei* were above the numbers expected in light traps if there was no difference between trap type.

Haufe and Burgess (1960) compared a visual attraction trap to a suction trap, which like a Malaise trap presumably takes a random sample of the flying insect population. They found that though a visual attraction trap caught ten times as many mosquitoes as a suction trap, there was no significant difference between the proportion of band-legged and black-legged *Aedes* between the two traps. At George Lake the main difference between Malaise I and the visual attraction trap was the low number of *Culiseta inornata* and the high number of *Culex territans* in the visual attraction trap and there were no significant differences in the proportions of *Aedes* species, which indicates that this trap takes a random sample of the mosquitoes which approach it. Haufe and Burgess (1960) found this trap caught all mosquitoes approaching to within about 30 inches of it and observations at George Lake support this.

The rotary trap catch was significantly different from the Malaise trap catch but this applies mainly to the catch of *Culiseta inornata* which was lower than expected and that of *Aedes punctor* which was higher than expected. In 1967 this species formed 58% of the catch. The evidence shows that this trap exerts an attractive stimulus to mosquitoes and this may be selective for some species, possibly *A. punctor.*

The animal bait traps differ from the others in that their attraction depends on the feeding habits of the adult female mosquitoes. Captures on chickens, rats and humans differed very little. Differences between human bait and the others were probably due to position.

Effects of carbon dioxide on the catch in Malaise traps

Rudolfs (1922) suggested that mosquitoes were attracted to carbon dioxide and since then some controversy has arisen over whether this is merely an activating agent (Willis, 1947; Laarman, 1955) or whether it also has an orienting effect (Reeves, 1953), but Clement (1963) states the importance of carbon dioxide as an aid in host finding by mosquitoes has yet to be determined.

Several workers have found that the addition of dry ice (solid carbon dioxide) to light traps greatly increases the catch (Reeves and Hammon, 1942; Huffacker, 1942; Huffacker and Bach, 1943 and Newhouse *et al.*, 1966). Carestia and Savage (1967) found that the catch in a C. D. C. miniature light trap was greatly increased by the addition of carbon dioxide from a cylinder and that the catch increased as the rate of flow was increased. Reeves (1953) used carbon dioxide as bait in a stable trap and caught large numbers of *Culex tarsalis* at 26 ml. CO_2 per minute (equivalent to one chicken) and the catch increased as the rate of flow increased. Bellamy and Reeves (1952) designed a portable trap, from a twenty pound lard can, which used dry ice as bait.

Hayes *et al.* (1958) and Dow (1959) have compared carbon dioxide bait with other mosquito attractants and find it compares very favorably as an attractant for adult females and Brown (1951) and Brown *et al.* (1951) have found carbon dioxide an effective attractant in the field.

Table 8 shows the catch of mosquitoes in Malaise + CO_2 traps and in Malaise traps over a period of six nights in 1966 and seven in 1967. The traps were run from 1700 hours to 0900 hours the following morning.

Table 8 Numbers of mosquitoes caught in Malaise and Malaise + CO_2 traps on equivalent nights at George Lake in July, August 1966 and May and June 1967.

Date	MI CO_2	MII	Date	MII CO_2	MI
1966					
27/28 July	79	4	28/29 July	134	2
2/ 3 August	253	0	3/ 4 August	24	4
4/ 5 August	152	1	9/10 August	48	8
10/11 August	30	1	17/18 August	27	1
18/19 August	39	2	23/24 August	27	0
24/25 August	36	2	31/ 1 September	4	1
Total	589	10	Total	264	16
Mw	48.2	1.3		28.5	1.8
Grand Total M+CO_2 853	Mw* 37.0				
Malaise 26	Mw 1.6				
1967					
16/17 May	13	3	17/18 May	14	0
24/25 May	1	1	23/24 May	17	0
30/31 May	2	0	31/ 1 June	457	5
7/ 8 June	452	7	8/ 9 June	1103	2
13/14 June	165	14	14/15 June	1590	5
21/22 June	240	4	22/23 June	536	6
29/30 June	207	13	28/29 June	1923	9
Total	1080	42	Total	5640	27
Mw	42.9	3.9		300.1	2.6
Grand Total M+CO_2 6702	Malaise 69				
Mw 114.1	3.0				

* Mw = Williams mean = antilog $\left[\frac{\Sigma \log (x+1)}{N}\right]$ -1

x = Number per sample

N = Number of samples

Table 9 shows the proportions of species in the Malaise and the Malaise + CO_2 traps. The complete Malaise trap captures are used, rather than only those on equivalent nights for these latter were too low for accurate analysis. These figures show that the addition of carbon dioxide to a Malaise trap greatly increases its catch and the numbers of nearly all species caught are increased. The increase for some species is greater than for others, *Aedes* species appearing to be more attracted to carbon dioxide than non-*Aedes* species. Three *Aedes* species showed significantly higher proportion in Malaise + CO_2 traps; these were

Table 9 Proportion of female mosquito species in Malaise and Malaise + CO_2 traps at George Lake.

Species	1966 (August)		1967 (May–June)	
	Malaise	Mal+CO_2	Malaise	Mal+CO_2*
Anopheles earlei	1.1 (1)	0.1 (1)	0.8 (4)	0.3 (22)
Culiseta alaskaensis	–	–	2.2 (10)	1.7 (115)
C. inornata	25.8 (24)	0.8 (8)	1.2 (6)	0.1 (7)
Other *Culiseta*	7.5 (7)	0.1 (1)	2.8 (13)	0.3 (21)
Culex territans	–	0.1 (1)	6.5 (39)	0.02 (2)
Mansonia perturbans	–	1.7 (1)	–	–
Total non-*Aedes*	34.4 (32)	2.8 (23)†	13.5 (63)	2.4 (160)†
Aedes cataphylla	–	–	1.8 (8)	0.9 (60)
A. cinereus	–	1.7 (11)	–	0.02 (3)
A. communis	–	0.5 (3)	4.4 (21)	3.0 (200)
A. excrucians	25.8 (24)	16.2 (102)	14.8 (69)	15.7 (1055)
A. fitchii	5.4 (5)	4.4 (27)	6.9 (22)	5.6 (375)
A. implicatus	–	0.1 (1)	19.8 (93)	21.3 (1430)
A. intrudens	–	–	6.3 (29)	16.4 (1120)**
A. punctor	6.5 (7)	5.7 (36)	14.8 (69)	23.0 (1540)**
A. riparius	3.2 (3)	3.5 (22)	13.2 (62)	6.3 (420)
A. vexans	23.7 (22)	61.4 (386)**	–	–
Other *Aedes*	1.1 (1)	3.6 (23)	4.6 (22)	5.4 (360)
Total *Aedes*	65.6 (61)	97.1 (611)	86.5 (405)	97.6 (6560)
Total	93	633	468	6720
No. species taken	9	15	16	25
a	3 ± 0.6	4 ± 0.5	3 ± 0.4	3 ± 0.3
	$\chi^2_7 = 184.484$	$P = < 0.001$	$\chi^2_7 = 235.787$	$P = < 0.001$

* Estimated total

** above expected in CO_2 trap

† below expected in CO_2 trap

Fig. in brackets = no. caught

A. vexans in 1966 and *A. intrudens* and *A. punctor* in 1967. *A. punctor* showed no significant difference in 1966 and in fact the proportion was slightly higher in the Malaise traps, possibly because this species is relatively less abundant in August than in the spring. The greatly increased proportion of *A. vexans* in carbon dioxide traps is interesting as Huffacker and Bach (1943) took a lower proportion of this species in light traps with carbon dioxide than in light alone, but Carestia and Savage (1967) and Newhouse *et al.* (1966) took slightly higher proportions of *A. vexans* in light traps with carbon dioxide than with light alone. Both Carestia and Savage and Newhouse *et al.* found the proportions of *Culex* species were greatly increased when carbon dioxide was added to light traps. This did not occur at George Lake as the only common *Culex* was *C. territans* which feeds mainly on amphibians.

Table 10 shows the Williams mean catch per trap night in Malaise, Malaise + CO_2 and light traps. To obtain some idea on how carbon dioxide attracts mosquitoes I watched both traps on several evenings in May and June in 1967. The traps had to be observed through binoculars from at least twenty yards distance; otherwise the mosquitoes left the trap for the observer. About half an hour after the traps were started, a swarm of mosquitoes formed over the catching head of Malaise I + CO_2, which was on low ground. At Malaise II + CO_2, which was on the top of a low ridge, no swarm formed but large numbers of mosquitoes settled on the baffles of the trap. I saw very few settling on these in Malaise I + CO_2. Many of the settled mosquitoes crawled or flew upwards and were caught.

In both traps many mosquitoes remained settled very close to the carbon dioxide outlet for periods of up to fifteen minutes.

The formation of a swarm over the carbon dioxide outlet and the very large numbers caught show that carbon dioxide probably exerts a considerable orienting stimulus to adult female mosquitoes; but it is easily overridden by the approach of a host animal such as man.

Table 10 Comparison of mosquito captures per night in Malaise, Malaise + CO_2 and Light traps at George Lake, July and August 1966 and May and June 1967.

	Malaise	Malaise+CO_2	Light
1966			
No. caught	26	589	69
No. of trap nights	12	12	26
Mw*/trap night	1.6	37.0	1.7
Range	0-8	4-253	0-14
1967			
No. caught	69	6720	130
No. of trap nights	14	14	30
Mw/trap night	3.0	114.1	1.4
Range	0-14	1-1923	0-59

* Mw = Williams mean

Physiological state

The contents of the ventral diverticulum. – Trembley (1952) and Hocking (1953) have shown that sugar solutions and nectar normally pass into the ventral oesophageal diverticulum and not into the stomach. Hocking (1953) has shown the importance of nectar as an energy source for mosquitoes. Thus, the contents of the ventral diverticulum are a partial measure of the energy resources available to the mosquito. The amounts of liquid in the ventral diverticulum in female mosquitoes caught in different trap types are shown in Table 11. In most mosquitoes the ventral diverticula were either empty or only partially filled; in only 30 out of 650 mosquitoes were they full.

There were no significant differences between trap types.

Table 11 Comparison of the contents of the ventral diverticulum of mosquitoes caught in the trap types at George Lake in 1966.

	Contents of Ventral Diverticulum				
Trap type	0	1	2	Mean	Total examined
Malaise	64	60	6	0.6	130
Mal+CO_2	78	38	4	0.4	120
Light	51	46	3	0.5	100
Vis. attr.	21	26	3	0.6	50
Rotary	25	39	4	0.7	68
Rat baited	45	49	3	0.6	97
Chicken baited	13	6	2	0.5	21
Coll. in trailer	22	37	5	0.7	64
Total catch	319	301	30	0.6	650

0 = empty
1 = partially full
2 = full

Ovarian development and stage in gonotrophic cycle. – Tables 12 and 13 show the stages of Sella and Tables 14 and 15 show the stages of Christophers. Table 16 shows the occurrence of gravid females in the traps. In 1966 light traps caught a significantly higher proportion of the higher stages than the other traps but this was not so in 1967. A striking difference between the two years was the large number of resting mosquitoes which had ovaries in stages III–V of Christophers in 1967, which has been discussed above.

Three gravid females were taken in animal bait traps and seven in carbon dioxide traps, but it is unlikely they were attracted to the bait.

Corbet (1961) found that in *Mansonia fuscopennata* (Theobald), in Uganda, light traps sampled only those specimens engaged in "non-specific activity" i.e., those not engaged in

Table 12 Comparison of the stages of Sella of mosquitoes caught in the different trap types at George Lake over the periods 1st June to 1st September 1966 and 16th May to 30th June 1967.

1966

	Stage of Sella								
Trap type	1	2	3	4	5	6	7	Mean	Total examined
Malaise	152	3	1	–	–	–	28	1.9	184
Mal+CO_2*	178	1	–	2	1	–	6	1.3	188
Light	95	1	1	1	1	3	75	3.7**	177
Vis. attr.	59	1	2	–	1	1	2	1.3	65
Rotary	77	1	2	2	–	1	4	1.5	87
Rat baited	124	6	–	–	–	–	–	1.0	130
Chicken baited	27	3	–	–	–	–	–	1.1	30
Trailer	76	2	–	–	1	–	–	1.1	79

* operated from 27th July to 1st September only

** $\chi^2_4 = 186.220$ $P = < 0.001$

1967

	Stage of Sella								
Trap type	1	2	3	4	5	6	7	Mean	Total examined
Total Malaise	129	–	1	–	–	2	2	1.2	134
Total Mal+CO_2	319	1	7	1	–	–	–	1.1	328
Total Light	108	2	–	–	–	–	–	1.0	110
Vis. attr.	48	1	–	1	–	–	–	1.1	50
Rotary	70	–	1	–	–	–	–	1.0	71
Rat baited	85	1	3	–	–	–	–	1.1	89
Trailer	43	7	10	10	5	4	6	2.6	85

swarming, biting, or ovipositing. Standfast (1965) confirmed this for *Culex annulirostris* Skuse but he believed this indicated activity in the intermediate stages of the gonotrophic cycle, that is females in stages III and IV of Christophers or III to VI of Sella. Corbet (1961), on the other hand, found 90% of *M. fuscopennata* in light traps were in stages I and II of Christophers and none were gravid. George Lake results do not support this since a number of gravid females and individuals in intermediate stages of the gonotrophic cycle were taken in light traps. Both Corbet and Standfast based their conclusions on the fact that peak light trap captures did not coincide with peaks of biting, swarming or oviposition activity. Captures were not recorded at hourly intervals at George Lake, but mosquitoes were often found biting round light traps in the evenings and in the mornings of nights when none were caught. Corbet and Standfast worked on tropical mosquitoes, which may explain some of the differences.

Table 13 Comparison of the stages of Sella of *Aedes* species in the different trap types at George Lake 1st June to 1st September 1966 and 16th May to 30th June 1967.

1966

	Stage of Sella								
Trap type	1	2	3	4	5	6	7	Mean	Total examined
Malaise	146	1	1	–	–	–	5	1.2	153
Mal+CO_2*	167	1	–	2	–	–	3	1.1	173
Light	63	–	–	–	–	–	6	1.5	69
Vis. attr.	46	–	2	–	1	–	1	1.3	50
Rotary	65	–	2	2	1	1	2	1.4	73
Rat baited	120	6	–	–	–	–	–	1.0	126
Chicken baited	27	3	–	–	–	–	–	1.1	30
Trailer	74	2	–	–	–	–	–	1.1	76

* only operated 27th July to 1st September
No siginificant difference

1967

	Stage of Sella								
Trap type	1	2	3	4	5	6	7	Mean	Total examined
Total Malaise	122	–	1	–	–	1	1	1.0	125
Mal+CO_2	276	1	6	–	–	–	–	1.0	283
Total Light	95	1	–	–	–	–	–	1.0	96
Vis. attr.	43	–	–	1	–	–	–	1.1	44
Rotary	69	–	1	–	–	–	–	1.0	70
Rat baited	84	1	3	–	–	–	–	1.1	88
Trailer	28	6	8	4	1	–	1	1.9	48

Physiological age of adult females as shown by the proportion of parous females. – In three years of study 1683 pairs of ovaries were examined for parity. The proportions of pars in the traps are shown in Tables 17–21. Except in August 1966, light traps caught a higher proportion of pars than other traps. In August 1966 the greater part of the light trap catch was *Culiseta inornata* and *Anopheles earlei*, most of which were probably about to overwinter and these species appear to overwinter as nullipars. All the *Aedes* taken in light traps in August 1966 were parous. The statistical significance of the higher proportion of pars in light traps is doubtful. In 1965 and 1966 the proportion of pars in light traps was significantly higher at the 5% level when tested against the rest combined but not significant when the traps were tested individually. In the spring of 1967, however, the proportion of pars in light traps was significantly higher at the 1% level when the traps were tested individually. In all cases the parity rate in light traps was higher for *Aedes* species than for the total catch.

Table 14 Comparison of the stage of Christophers of mosquitoes in different trap types at George Lake from 1st June to 1st September 1966 and 15th May to 30th June 1967.

1966

Trap type	Stage of Christophers I	II	III	IV	V	Mean	Total examined
Malaise	57	80	8	5	23	2.2	173
Mal+CO_2*	77	94	2	1	6	1.7	180
Light	30	51	7	6	71	3.2**	165
Vis. attr.	27	28	3	1	2	1.7	61
Rotary	29	45	3	2	4	1.9	83
Rat baited	43	78	–	–	–	1.6	121
Chicken baited	5	21	–	–	–	1.8	26
Trailer	32	41	4	–	–	1.6	77

* only operated 27th July to 1st September

** significant at 1% level $\chi^2_4 = 198.005$ $P = < 0.001$

1967

Trap type	Stage of Christophers I	II	III	IV	V	Mean	Total examined
Malaise	32	97	1	2	2	1.8	134
Mal+CO_2	100	216	9	–	2	1.7	327
Light	19	87	1	–	–	1.8	107
Vis. attr.	11	37	2	–	–	1.8	50
Rotary	13	54	3	–	–	1.8	70
Rat baited	14	71	2	–	–	1.9	87
Trailer	7	50	16	6	6	2.4	85

Table 21 shows the parity rate in five species taken in different trap types. With the exception of *Anopheles earlei* the parity rate in light traps was higher than in other traps. It is clear that light traps have a slightly higher attraction for older female mosquitoes than the other trap types tested.

Damage to mosquitoes by different collection methods

I noticed that the condition of specimens caught in different traps varied considerably. I investigated this using six arbitrary damage categories. The results are shown in Table 22. The specimens taken in Malaise traps both with and without carbon dioxide are in much better condition then those taken in other traps, probably because the insects were dead before falling into the collecting bottle and there were no moving parts in the traps. These traps also involved a minimum of handling both during and after capture. The rotary trap

Table 15 Comparison of the stage of Christophers of *Aedes* species in different trap types at George Lake, 1st June to 1st September 1966 and 16th May to 30th June 1967.

1966

	Stage of Christophers						
Trap type	I	II	III	IV	V	Mean	Total examined
Malaise	55	77	8	1	5	1.8	146
$Mal+CO_2$*	75	92	2	–	4	1.7	173
Light	12	45	4	–	6	2.2**	67
Vis. attr.	21	22	2	1	1	1.7	47
Rotary	23	39	3	2	1	1.8	68
Rat baited	43	72	–	–	–	1.6	115
Chicken baited	5	21	–	–	–	1.8	26
Trailer	31	40	4	–	–	1.6	75

* only operated 27th July to 1st September
** significant at 1% level. $\chi^2_3 = 19.27$ $P = < 0.001$

1967

	Stage of Christophers						
Trap type	I	II	III	IV	V	Mean	Total examined
Total Malaise	32	89	1	1	1	1.8	124
$Mal+CO_2$	100	171	7	–	2	1.7	280
Total Light	17	76	1	–	–	1.8	94
Vis. attr.	10	32	2	–	–	1.8	44
Rotary	13	53	3	–	–	1.8	69
Rat baited	14	70	2	–	–	2.0	86
Trailer	7	33	10	1	1	2.2	52

damaged specimens more than any other and the mean shown is possibly too low as the catch of this trap included a high proportion of unidentified specimens which were not assigned to any damage category.

General discussion

Southwood (1966) has reviewed methods of sampling insects, including mosquito populations. Though a great deal of ingenuity has been expended on the design of methods for sampling adult mosquito populations and on the refinement of these methods, they are mainly aimed at the largest possible catch. A few methods have been designed for special purposes such as window traps (Muirhead-Thompson, 1951) which are designed to catch mosquitoes entering or leaving buildings, a trap to catch mosquitoes emerging from cesspits (Saliternik, 1960) and several traps designed to catch resting mosquitoes (Russell and San-

Table 16 Occurrence of gravid female mosquitoes in the different traps at George Lake in 1965, 1966 and 1967.

Species	Mal I	Mal II	Mal I + CO_2	Light I	Light II	Visual Attr.	Rotary	Animal baited	Trailer	Total
Anopheles earlei	–	–	1	2	–	–	1	–	4	8
Culiseta alaskaensis	2	–	–	–	–	–	–	–	–	2
C. inornata	31	–	–	93	6	–	–	2	–	132
Culex territans	1	1	–	–	–	1	1	–	1	5
Aedes communis	1	–	–	–	–	–	–	–	–	1
A. excrucians	1	–	1	–	1	1	2	–	–	6
A. implicatus	1	1	–	–	–	–	–	–	1	3
A. intrudens	–	–	1	–	–	–	–	–	–	1
A. pionips	–	–	–	1	–	1	–	–	–	2
A. vexans	4	–	1	2	3		1	–	–	11
Unidentified	–	–	–	–	–	–	–	1	–	1
Totals	41	2	4	98	10	3	5	3	6	172

Table 17 Proportion of parous mosquitoes in trap types at George Lake 1st June to 1st September 1966.

Trap type	Parous	Nulliparous	P:N+P
Malaise	57	87	0.40
Light	49	41	0.49**
Vis. attr.	19	36	0.34
Rotary	32	43	0.42
Rat baited*	42	50	0.46
Coll. in trailer	30	43	0.41
Total	229	300	0.43

* Operated 27th July to 1st September only

** significant at 5% level for those traps run for the whole period.

$\chi^2{}_2 = 5.447$ (Light vers. rest) $P = < 0.05$

Table 18 Comparison of like proportion of parous mosquitoes in trap types operated in August 1965 and August 1966 at George Lake.

Trap type	1965			1966		
	Par	Null	P:N+P	Par	Null	P:N+P
Malaise	12	10	0.54	19	11	0.64
Mal+CO_2	Not done	–	–	82	30	0.73
Light	30	13	0.70	15	10	0.60*
Vis. attr.	5	7	0.42	7	2	0.78
Rotary	1	3	0.25	11	1	0.92
Animal baited	24	15	0.62	40	11	0.78
Trailer	Not done			8	3	0.73
Total	72	48	0.60	182	68	0.73
		not significant			not significant	

* all 13 *Aedes* species caught were parous.

Table 19 Comparison of the proportion of parous mosquitoes taken in various trap types at George Lake in June 1966 and 1967.

Trap type	June 1966			May, June 1967		
	P	N	P:P+N	P	N	P:P+N
Malaise	17	43	0.28	17	115	0.13
Mal+CO_2	–	–	–	51	278	0.16
Light	13	18	0.42	37	112	0.25
Vis. attr.	8	24	0.25	3	44	0.06
Rotary	8	27	0.22	14	57	0.20
Rat baited	17	31	0.35	9	78	0.10
Total	63	143	0.31	131	684	0.11

no significant difference between traps at 0.05 level $\chi^2_5 = 15.75$ $P = < 0.005$

Table 20 Comparison of the proportion of parous *Aedes* females at George Lake in trap types operated for the whole period, 1st June to 1st September 1966, and May and June of 1967.

1966

Trap type	Par	Null	P:N+P
Malaise	52	85	0.38
Light	35	25	0.58
Vis. attr.	14	28	0.33
Rotary	25	27	0.48
Rat baited I	38	48	0.44
Coll. in trailer	29	42	0.41
Total	193	265	0.42

$\chi^2_2 = 7.967$ $P = < 0.01$ (light vers. rest)

1967

Trap type	Par	Null	P:N+P
Malaise	17	109	0.15
Malaise CO_2	32	243	0.12
Light	26	68	0.28
Vis. attr.	3	38	0.07
Rotary	14	56	0.20
Rat baited I	8	77	0.09
Total	100	591	0.14

$\chi^2_5 = 20.14$ $P = < 0.001$

Table 21 Comparison of the proportion of parous females of selected mosquito species in trap types at George Lake (Results for 1965, 1966 and 1967 combined).

Trap	Species *Anopheles earlei*	*Culiseta inornata*	*Aedes excrucians*	*A. punctor*	*A. vexans*
Malaise	0.50 (4)	0.60 (15)	0.30 (79)	0.16 (37)	0.66 (21)
Light	0.54 (28)	0.63 (19)	0.56 (55)	0.35 (31)	0.70 (20)
Vis. attr.	0.42 (12)	0.14 (7)	0.25 (20)	0.25 (24)	0.50 (4)
Rotary	0.67 (6)	0.00 (3)	0.33 (9)	0.27 (45)	0.17 (6)
Bait	–	0.5 (4)	0.38 (57)	0.14 (49)	0.36 (14)

Figure in brackets = no. examined

Table 22 Comparison of the damage done to mosquito specimens by different trap types.

Trap type	Damage Category* 0	1	2	3	4	5	Mean	Total examined
Malaise	40	38	73	12	16	3	1.6	182
Mal+CO_2	44	48	65	21	5	2	1.5	185
Light	8	16	31	23	43	31	3.1	152
Vis. attr.	8	6	23	6	19	10	2.7	72
Rotary	0	4	13	16	36	25	3.9	84
Rat baited	5	7	40	23	54	21	3.2	150
Chicken baited	2	4	11	9	7	8	2.9	41
Coll. in trailer	7	10	45	35	13	16	2.9	126

* Key

0. Pristine, unrubbed, very fresh appearance.
1. Very good, unrubbed, but not so fresh.
2. Good, some mesonotal scales missing but pattern clearly discernible.
3. Fair, mesonotum rubbed, but species still identifiable by scale pattern.
4. Rubbed, mesonotum with most scales missing, species not identifiable by scale pattern.
5. Bald, almost all scales missing, black legged *Aedes* sp. rarely identifiable.

tiago, 1934; Smith, 1942; Snow, 1949; and Muirhead-Thompson, 1958). These methods are usually biased towards a few species. Many resting-site methods have been designed to catch anopheline vectors of malaria. Methods designed for general survey work should catch as wide a spectrum of species as possible and should not be selective for any species or physiological state.

A large number of factors affect the efficiency of sampling methods. One of these is geographical location. The pit shelter (Muirhead-Thompson, 1958), was designed and worked well in Rhodesia and in Java (D. A. Muir, *pers. comm.*), two areas very different in climate and with very different mosquito species but failed when tried in Sarawak, an area similar in climate and with many mosquito species in common with Java. The methods I tested were all designed to be of use in general survey work. The findings may apply only to central Alberta but should also apply to much of the southern part of the boreal forest in which similar conditions and species occur. The mosquito fauna of this area is peculiar for the great preponderance both in the numbers and in the number of species of *Aedes* and the relative unimportance of all other genera except *Culiseta*. At George Lake five genera were found but *Aedes* comprised 72% of the species and 85% of the individuals. This can be compared to Kentucky, where eight genera were found and *Aedes* comprised 31% of the species and 52% of the individuals (Breeland and Pickard, 1965). It is thus improbable that findings in one area will apply *in toto* to the other.

The importance of the physiological state of the mosquitoes has been ignored in most studies on sampling adult mosquito populations. Bursell (1961) showed that the physiological state of tsetse flies (*Glossina swynnertoni* Austen) varies according to the sampling method used and this greatly affected interpretation of the results. Differences in the physiological age of mosquitoes taken by different sampling methods could affect the results in disease transmission studies as mosquitoes only become infected with disease-causing microorganisms after they have fed on an infected host. Thus a trap which takes a higher proportion of physiologically older females than occur in the population will give an exaggerated infection rate and if the method is selective for a few species may cause the vectorial importance of some species to be overrated. Though such a method may be useful where infected females are rare or a pool of mosquitoes is used and an exact infection rate is not required.

The low activity of the adult females in stages III and IV of Christophers is important and must be taken into account in population studies using sampling methods which catch active mosquitoes, as this means that a significant proportion of the population is inactive and so unavailable for sampling. Most studies, including this one, which show population peaks of mosquitoes are actually showing peaks of activity rather than actual population peaks and though the activity and population peaks are probably similar, this is by no means certain. Methods of capturing resting adult female mosquitoes are inaccurate, biased towards a few species and almost impossible to correlate with methods of taking active mosquitoes. If the length of the gonotrophic cycle at different temperatures and the average number of gonotrophic cycles passed through by the females in a population were known, an estimate of the proportion in the stages III and IV of Christophers could be obtained. Polovodova's method enables the number of gonotrophic cycles passed through by a female mosquito to be accurately determined and work on this in North America has been started both on

Culex tarsalis (Nelson, 1964; Burdick and Kardos, 1963) and on univoltine *Aedes* species (Carpenter and Nielsen, 1965), but almost nothing appears to be known of the length of the gonotrophic cycle in most North American species of mosquito. This is a fruitful field for future research. The use of Polovodova's method in determining the life history, vectorial importance and population dynamics of *Anopheles maculipennis* Meigen is shown by Detinova (1962).

The contents of the ventral diverticulum provide a partial measure of the energy reserves available to the mosquito. Theoretically it should be possible to distinguish the proportion of mosquitoes which have recently migrated into an area; these should have empty or nearly empty ventral diverticula, having used up most of their energy resources on the flight and the resident population should have full or nearly full diverticula. However, it would be necessary to conduct a thorough investigation of the nectar resources available and of the plants frequented by mosquitoes before the contents of the ventral diverticulum could be used to distinguish migrants from resident mosquitoes. At George Lake the majority of mosquitoes had empty or only partially filled ventral diverticula in 1966. Since flowers were abundant during the whole of the investigation, it is possible that many of the mosquitoes caught had migrated in from outside the field site; this is supported by the very few larvae found near the study area and the few males caught. Males are believed to be more sedentary than females, seldom moving more than a few miles from breeding sites, while adult female *Aedes* in temperate regions may undertake long distance migrations (Clement, 1963).

Since male mosquitoes do not take blood meals, relatively little attention has been paid to them in the past, as is shown by the few references to males in Bates (1949) and Clement (1963). I paid little attention to male mosquitoes in this study. In the last few years the development of sterile male methods of insect control has resulted in considerable interest in male mosquitoes. Males probably give a better idea of the population breeding in the vicinity of the study because they are more sedentary than the females and the adult males of many species provide more reliable characters for specific determination than do the adult females. It is unlikely that any one method will be equally effective for sampling both adult females and adult males because their biologies differ considerably. The swarming habits of the males of many species of mosquito will make the siting of traps even more critical for males than females and this, coupled with the fact that females appear to be longer lived than males and as they only mate once, it is unlikely that any one sampling method will give a true sex ratio. The important sex ratio, the number of males to unmated females, can probably be best estimated from rearing experiments.

Methods believed to take a random sample of the active population. – Malaise traps exert no recognizable attraction to mosquitoes and so I believe they take a random sample of the active mosquitoes and that this is unbiased both towards species and towards physiological state. There is one possible area of bias, that is, against blood meal seeking mosquitoes. If the generally accepted theory of host finding in mosquitoes, which is, that the biting cycle represents the frequency with which a population in random flight comes within the range of attraction of a host (Mattingly, 1949), is correct then there is no bias. However, Corbet (1961) has shown that there may be a definite urge to bite and it is possible that some mosquitoes with this urge may rest on the vegetation until activated by the presence of a possible host as do tsetse flies (*Glossina* species) (Glascow, 1963). If this is so then not many hungry mosquitoes will be caught in Malaise traps which would introduce an element of physiological bias.

At George Lake the proportion of the rarer species in Malaise traps was less than in traps which used an attractive element. This indicates that these traps are unlikely to catch large samples of these species, though they took a larger number of species than any other trap type probably because of the longer operating time. The four species not taken in Malaise traps were all rare, no more than two specimens of each being taken by all methods in 1966. No species were taken by Malaise traps alone. Breeland and Pickard (1965) found that Malaise traps caught a higher proportion of rare species and several species they recorded were only taken in Malaise traps.

The Malaise trap has certain advantages over other traps; it has no moving parts; it can work with a minimum of servicing, and needs to be emptied only once or twice a week, which allows it to be operated in remote places; it operates twenty-four hours a day and the catch is preserved in good condition. A few disadvantages are important; if left for any length of time spiders spin webs across the entrances; it is very vulnerable to vandalism; low efficiency and large size make it necessary to operate this trap for a prolonged period in a single site and the position of the trap is more critical than for other trap types; many mosquitoes which enter the base of the trap get attracted out before they are caught, so that the number seen round the traps is no indication of the catch; and it is very difficult to obtain a meaningful estimate of the volume of air filtered and so obtain an absolute density figure. These disadvantages may preclude the use of Malaise traps for some studies.

Smith *et al.* (1965) found Malaise traps alone were capable of predicting outbreaks of biting flies in Kentucky. The advantages listed above make this trap superior to most other presumably unbiased methods of collection where absolute density figures are not required.

Suction traps (Southwood, 1966) require a motor or permanent electric supply and require regular servicing. The position of these traps is critical as in Malaise traps. The volume of air filtered can be easily obtained so this trap can give an absolute density figure for flying mosquitoes.

A fairly recent innovation is a net attached to a car. These have been used by Stage and Chamberlin (1945), Biddlingmayer (1964, and 1967) and Sommerman and Simmet (1965). Provided the car is driven fast enough to eliminate attraction to moving bodies these nets probably give a random sample of active insects. The period of operation is limited but this method can cover a wide area. Sommerman and Simmet (1965) have provided a design that enables the catching container to be changed at distance or time intervals, which makes the results easier to interpret. If driven along the same route at the same time of day at regular intervals this method should produce useful results, but a series of Malaise traps at strategic intervals would probably provide as useful if not more useful information at less cost.

The rotary trap is generally considered to take a random sample of flying insects and the volume of air filtered can be easily determined, so if this trap had no attraction for mosquitoes an absolute density figure would be given. But the randomness of the sample taken in these traps is open to doubt as the traps almost certainly exert some attractive stimuli to mosquitoes and these may be selective for some species. Also, Maw (1964) has shown that the nets can become charged with static electricity and repel some small flying insects. This trap is bulky, requires considerable attention and damages the catch. I do not believe rotary traps can supply data that cannot be obtained equally well by Malaise traps.

Much the same is true of the visual attraction trap, though this trap probably does take a random sample of active mosquitoes.

If a random sample of active mosquitoes over a prolonged period is required and absolute density figures are not necessary, Malaise traps can obtain this with less trouble than any type of mechanically operated trap and are just as capable of detecting variations in population level. Where a large sample is required or only a limited time is available some other method such as visual attraction or car trap will possibly be better.

Methods known to take biased samples of the population. – Methods which use light, a bait or which capture mosquitoes in resting places are considered here.

A large number of designs of light traps for insects have been described (Southwood, 1966), but relatively few are suitable for mosquitoes. Many small insects including mosquitoes are repelled by strong light (Verheijen, 1960; Barr *et al.*, 1963) and so traps designed to catch these usually include a suction fan, like the New Jersey trap. Loomis (1959) considered that the air flow through a New Jersey trap must be standardized if two traps are being compared. At George Lake in 1966 the number of mosquitoes per 10,000 cubic feet of air filtered was 0.73 in Lt. I and 0.25 in Lt. II which are in the same ratio as the catches per 100 trap hours are (2.9). This shows that the difference between the catches in the two traps was not due to difference in air flow through them.

The species composition of light trap captures is usually considerably different from that in the natural population. This has been shown by Southwood (1960) for Heteroptera and it has also been found in mosquitoes. The attraction to light may vary within a single species over its geographical range and under different environmental conditions. *Anopheles earlei* was one of the species in which a high proportion of the catch was taken in light traps at George Lake, but McLintock *et al.* (1966) found a much lower proportion of this species was taken by light traps than in collections by other methods in Saskatchewan.

Light traps can only provide data on relative changes in mosquito populations and are probably of little use in life-table studies or in studies in which the true species composition of the mosquito fauna is required. In spite of many drawbacks, light traps are useful survey tools for mosquitoes and, if the attraction for older (parous) mosquitoes is found to be widespread, will prove especially useful in some disease transmission studies. Light traps are easily standardized and if run in the same place over a long period give an indication of population changes. Clark and Wray (1967) used light traps in studies which enabled accurate prediction of *Aedes vexans* invasions of Illinois cities. Few modern workers would go as far as Mulhern (1953), who stated that since light traps were mechanized they gave better results than methods involving collection by hand, such as human biting rate collections, since these have a human element in them.

Light traps are particularly efficient for male mosquitoes (Belton and Galloway, 1965; Southwood, 1966) and they are probably the most efficient method of sampling males. Light traps were not very effective at George Lake because it is near the northern limit at which light traps are useful.

Animal bait traps are often used and collections of mosquitoes settling on man have frequently been used to obtain density figures for mosquitoes. Human baited traps are described by Gater (1935) and Klock and Biddlingmayer (1953), and traps baited with large animals by Magoon (1935), Shannon (1939), Bates (1944) and Roberts (1965). Wharton *et al.* (1963) modified a Malayan trap (Gater, 1935) for use with monkeys as bait. In recent years interest has arisen in mosquitoes which attack birds, in connection with studies on arbor viruses, and several traps baited with chickens or other birds have been described (Flemings, 1954 and Rainey *et al.*, 1962). Lumsden (1958) and Worth and Jonkers (1962) have designed traps which use small vertebrates as bait. The Lumsden trap uses a fan and can give timed captures; portable versions of it are described by Snow *et al.* (1960) and Minter (1961).

The advantages of small mammal traps seem to be great. At George Lake captures in rat baited traps were very similar in composition to human bait captures, so white rats appear to have great value as bait in mosquito surveys. They are hardy, can survive outdoors if given shelter and can be left unattended for several days. As they give an approximation of the human biting rate they will give an idea of the nuisance value of the mosquito species present. Human bait captures while very useful can only be done for limited periods and are more expensive. Birds require more attention and large traps and, while essential in some virus transmission studies, they may give a false impression of the species composition, in studies where nuisance to man is important.

The only animal-substitute bait tested was carbon dioxide. When added to a Malaise trap this greatly increased both the catch and the number of species per unit time, but it appears to be especially attractive to some species, destroying the random nature of Malaise trap captures. For most purposes this is probably not too great a disadvantage and the increased catch will offset this, as the species attracted will probably be pest species.

The erratic behaviour of the dry ice trap of Bellamy and Reeves (1952) was possibly due to the small entrance area since the orienting stimulus of carbon dioxide appears to be weak. The main disadvantage of the addition of carbon dioxide from a cylinder to Malaise traps is that it is expensive and cannot be operated in remote places. However, dry ice is reasonably cheap and when in large enough blocks and suitably packed can last for several days while emitting large quantities of carbon dioxide. I believe that a useful mosquito trap for general survey purposes in places which cannot be visited every day would be a Malaise type trap modified to use dry ice as a bait. In central Alberta 25 pounds of dry ice lasts two to three days, which would make it possible to service this trap at bi-weekly intervals. Alone or combined with small mammal bait traps these traps could be operated in places several miles from a city, close to major mosquito breeding areas, and provide accurate data for forecasting the need for control measures in the city.

Olkowski *et al.* (1967) found Malaise traps baited with dry ice caught significantly more tabanids (Diptera; Tabanidae) than did unbaited traps in California. At George Lake tabanids were too scarce and erratic in occurrence for any conclusions to be drawn. Anderson *et al.* (1967) found the same proportion of the population of *Symphoromyia* (Diptera; Leptidae) were taken in Malaise traps baited with dry ice as were attracted to their natural hosts. They considered that these traps could give equivalent information on factors influencing attack rates at a lower cost, as could direct observation and collection of the flies from the hosts.

Collections in resting sites are useful for a few limited purposes, especially for obtaining blood fed females for host determination (World Health Organization, Division of Malaria Eradication and Lister Institute of Preventive Medicine, 1960) or for obtaining detailed information on the resting habits of mosquitoes for control with residual insecticides (Muirhead-Thompson, 1951). These methods have proved very valuable in studies on anophelines but less successful for northern *Aedes*.

Results from central Alberta (Graham in Prep. and Happold, 1965) indicate that no local *Aedes* species exhibit any special tendency to enter buildings, but *Anopheles earlei, Culiseta inornata* and *Culex tarsalis* are known to hibernate in basements. Shemanchuk (1965) has shown that the principal hibernation sites of these species are in animal burrows. Further studies on the resting habits of Alberta mosquitoes are required.

Conclusions

The principal conclusions drawn from this study are that the position as well as the trap type greatly affects the size and composition of the catch. Malaise traps both with and without carbon dioxide are probably the most useful types of traps for general mosquito survey work as they can be operated away from sources of power and need relatively little attention. Light traps will continue to be very useful in mosquito surveys, especially inside urban areas, as long as their limitations are clearly understood. Animal bait and resting-site captures are useful for specific purposes. Human bait captures are particularly useful for assessing mosquito nuisance and should always be used by urban mosquito control organizations in conjunction with other sampling methods but are of little value alone for forecasting the need for adult control measures in cities.

Although not tested in this study, car trap captures will probably be very useful in areas where vandalism or other factors prevent the use of Malaise or animal bait traps outside the city limits, but they should not be used instead of these.

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