certain shallow water areas. In this method, the lower part, or that portion of a marshy area toward the lake, is deepened and the earth obtained is spread upon the upper half of the marsh. Such displacement of earth creates a steep bank of 2 to 4 feet, and is a permanent method of eliminating trouble areas. Unfortunately, this would not be practical on the main reservoir as the 8 foot seasonal recession would pull the water below the bank and the deepened area before the end of the breeding season.

Growth Invasion Studies. In order to observe the extent of marginal growth invasion, lines of stakes at about 6 inch contour intervals will be set in typical areas around the reservoir. Mosquito production and larvicidal expenditures may later be correlated with this growth invasion index.

Aerial Spraying. A 30% DDT solution will replace the 20% solution used last year. By doing this a saving is anticipated in both flying time and solvent. In the way of deterring mosquito resistance to DDT, greater effort will be made to apply only minimum dosages to larvae this season. A large scale experimental adulticiding program will be done by airplane in the evening and the results determined by biting counts and light traps.

NOTES ON THE ACTIVITIES OF *AEDES* LARVAE

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Introduction: Animals which feed by the filtration of a stream of water are commonly sedentary or sessile. This is apparently partly because they can bring food to themselves instead of having to go and fetch it, but more because this method of feeding rarely permits the accumulation of sufficient energy reserves for extensive or violent movement (e.g. Jørgensen, 1952). If the characteristic wriggling of mosquito larvae is their normal activity state, as many writers apparently believe (e.g. Matheson, 1944, pp. 31 & 32) they represent a striking exception to this in that they are left with sufficient energy reserves to permit an unusual degree of activity in the pupal stage also.

These observations were made in an attempt to elucidate this riddle, and as a preliminary to more extensive studies of the energetics of the mosquito adult (Hocking, *in press*).

Diurnal movements: Most observations were made on a large population of larvae of *Aedes communis* De Geer in a single pool (fig. 1) near Churchill, Manitoba.

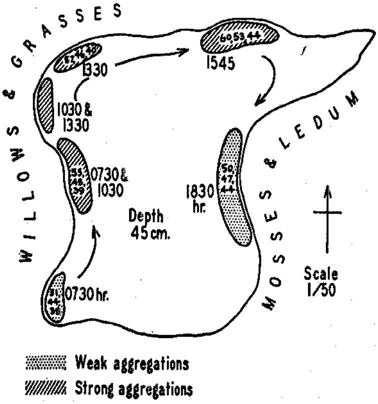

Fig. 1. Changes in the position of aggregations of the larvae of *Aedes communis* through the day. 5 June, 1951. Figures within the aggregations are fahrenheit temperatures at the top, middle depth, and bottom.

This was watched for total periods of up to 6 hours on selected days during larval development. There were few larvae of any other species present.

On sunny days, when the larvae were mostly in the 2nd or 3rd instar, they formed conspicuous aggregates which permitted the observation of a general circulatory movement around the pool. Aggregates were formed at the surface of the pool, in the shallows which were receiving sunlight most strongly, and were never seen on a completely overcast day. Up to 1003 larvae were obtained in a single dip with a 400 cc. dipper from aggregates; the average number elsewhere in the pool was 20, most of them 1st or 2nd instar.

To investigate the direct effect of sunlight, a dipper of larvae was placed in the sun so that one half was shaded. In a few minutes, most of the larvae had assembled in the shaded side (fig. 2, top.) The dipper was then rotated through 180°, so that the shaded and sunny sides were reversed; this was done slowly so that the water and larvae moved with the dipper. The photograph in fig. 2, bottom, was taken 30 sec. after this reversal; the intense aggregate in the middle of the sunny side persisted for 4 or 5 minutes, breaking up by the movement of larvae from the margins, towards the shaded side of the dipper. It seems that, in spite of the photokinesis resulting in a general tendency to aggregate in the shaded area, sunlight may contribute to the formation at least of temporary aggregates, presumably through a form of the phototelotaxis described by Muirhead-Thomson (1940) for *Anopheles minimus,* the larvae orientating mutually towards their shadows.

Temperature perhaps may play a more important part in the formation of aggregates than light; Ivanova (1940) has shown that the larvae of *Anopheles maculipennis* when placed in a temperature gradient tend to move to an optimum temperature zone. The temperatures at the top, middle depth, and bottom, taken at the time of the first observation after aggregation are shown in fig. 1. On only one occasion were temperatures higher than those in existing aggregates recorded elsewhere in the pool; at 1545 hr. the temperatures near the SE corner were 61, 52, 43° F.

FIG. 2, top. Larvae of *Aedes communis* aggregating in the shaded side of a 400 cc. dipper.

FIG. 2, bottom. 30 seconds after rotating the dipper through 180°. Aggregates forming in the sun and shade.

Under undisturbed conditions there appeared to be little activity beyond local feeding movements, and this steady drift of aggregates around the pool on sunny days.

Methods of progression: These diurnal circumnavigations appear to be accomplished with little assistance from the supposedly normal wriggling method of locomotion. Nearly all motion was with the aid of the feeding current set up by the mouth brushes. Indeed there were only three circumstances in which wriggling appeared to be the normal activity. Firstly, as an alarm reaction in response to a major disturbance; secondly, in coming up to the surface after diving; and thirdly, a very brief action in breaking away from the surface film for a dive. All other movements, at or below the surface were accomplished by means of the mouth brushes; a much more economical activity.

Presumably the movement of the mouth brushes which is used in locomotion is similar to that used in the "interfacial feeding" described by Renn (1941) in *Anopheles quadrimaculatus* and *A. crucians*, which would give a larger resultant force than would eddy feeding. It is evident, however, that the direction and magnitude of the force can be precisely controlled; the effect of this can be seen in the variation in the angle at which larvae hang from the surface film (fig. 3). Surface tension acts vertically upwards at the tip of the siphon which serves as a pivot. The buoyancy of the water acts vertically upwards at the centre of buoyancy. This is probably posterior to the centre of gravity, at which the weight acts vertically downwards, since the tail is normally above the head. Mosquito larvae are usually slightly heavier than water, that is, the weight is slightly greater than the buoyancy. If larvae are to hang in any position in which the centre of gravity is not vertically below the siphon, an additional force is necessary with a moment about the tip of the siphon proportional to the sine of the inclination of the body axis to the vertical. This force seems to be provided by the reaction set up by the feeding current.

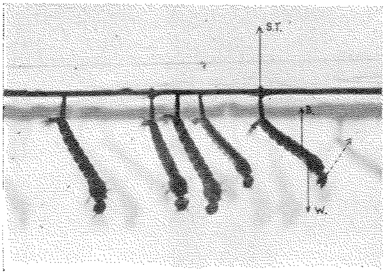

FIG. 3. Angles made by larvae of *Aedes communis* with the surface film.

The force resulting from the feeding current is apparently also utilized in a peculiar variant in feeding behaviour which has been observed especially in the younger larvae of *A. communis, A. pionips*, and *A. stimulans* and probably other species. This involves a circling movement which has been mentioned by Bates (1949). The larva lies parallel to the surface after the manner of *Anopheles spp.*, but the head is not reversed, and the food current comes from below the surface. The larva rotates about its siphon. There may be an overall movement in one direction superimposed on this, so that the path travelled by the head approaches a cycloid. This movement seems to be accomplished by a twisting of the head about the long axis of the body—an approach to the completely reversed condition of *Anopheles*—this brings the mouth brush on one side closer to the surface film which perhaps enhances its effect. It is as if the larva "walks" around the circle with one mouth brush, on the underside of the surface film. Movements of the two brushes remain synchronous. Rotation may be in either direction. Sometimes the head and thorax are turned towards the direction of rotation. Rotation is then usually faster.

The following figures were obtained for the frequency of brush movement, rates of rotation and forward movement for *A. communis* (averages of 4 readings). Giles (1902, p. 129) cites Nuttall as giving a frequency of 3 cycles/sec. for this movement in *Anopheles*.

Stimuli which evoke diving: To obtain a better knowledge of the extent of wriggling activity under natural conditions, the stimuli required to evoke diving were investigated. The effect of ground movements in muskeg areas on mosquito larvae has already been reported (Hocking *et al.*, 1950). A further study of this was

TABLE 1. The frequency of mouth brush movement and rates of rotation and progression. *Aedes communis* larvae

	Mouth brush frequency, cycles/sec.	Rotation, rev./min.	Speed, cm./sec
1st instar	4.2	4	0.21
2nd instar	5.3	3.2	0.28

made, and it was found that the larvae dived in response to ground movements only if these were of sufficient magnitude to result in visible surface ripples on the pools. When such ripples were produced by other means such as touching the surface with a stick or dropping in a very small stone, larvae and pupae dived as the circular ripple reached them. Almost all larvae returned to the surface within one minute.

Diving could also be evoked by visual stimuli. When opaque objects of various widths were moved parallel to the surface of the pool, larvae would dive as the object approached them. This was evidently not a shadow effect; the response was the same under sunny and overcast conditions. If the object were moved very rapidly, however, there was no response. The limiting distance above the water surface at which a response could be obtained with a given object depended on its width. By measuring these widths and distances, it was found that 2nd and 3rd instar larvae would respond only if the angle subtended by the object at the heads of the larvae, were greater than from 17° 30′ to 21° (average 19° 15′). A few observations were made on 4th instar larvae and pupae, which would respond at angles down to about 10°. This suggests that objects subtending smaller angles than these could not be resolved by the larval eyes, i.e., that the visual acuity of 2nd and 3rd instar larvae is about 0.00087, that of 4th instar larvae and pupae, about 0.0017. Hecht and Wolf (1929) recorded a maximum visual acuity of 0.017 for *Apis* and Hecht and Wald (1934) recorded 0.0018 for Drosophila (man 2.0–2.5). Thomas (1950) has reported that water vibrations and changes in light intensity are the stimuli which evoke diving in *Culex fatigans,* but found a decreased response in older larvae. Gordon (in Bates, 1949) found the larvae of *Anopheles darlingi* sensitive to a decrease in light intensity, but not to an increase.

Under natural circumstances in the north, these stimuli required for diving and wriggling activity are seldom provided. Rainfall, wind blown debris landing on the surface of a pool, and the visits of larger animals are perhaps the commonest events providing them. Larvae have been seen to dive in response to a bird flying very low over the pool. Their reactions to rain might well be studied. Perhaps the excessive demand for both larval and pupal wriggling in laboratory rearing, which is presumably largely responsible for their unfounded reputation for continuous activity, is also a major cause of mortality in the laboratory.

Summary: Observations on the natural activities of the larvae of *Aedes spp.* especially *A. communis* DeG. indicate that these are much less intense than has been commonly believed. Wriggling locomotion is rarely used in natural conditions; most movements are accomplished by means of the mouth brushes. The use of surface feeding with a circling movement, by these species, is described. An explanation of it is suggested. The mechanical and visual stimuli which evoke diving are described.

Acknowledgment: Some of these observations were made during the course of other studies while in the employ of the Medical and Veterinary Entomology Unit, Division of Entomology, Canada Department of Agriculture.

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STUDIES ON FINE SPRAY AND AEROSOL MACHINES FOR CONTROL OF ADULT MOSQUITOES[1]

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During 1951 and 1952 a comparative study was made of 5 machines for their ability to control infestations of adult *Aedes* mosquitoes about camps in Canadian woodland. They comprised the Microsol generator (Wilson *et al.*, 1949), the Husman sprayer,[4] a recent modification of the Besler generator (Brescia, 1946; Wilson *et al.*, 1949), the TIFA machine (Dickinson *et al.*, 1948; Horsfall, 1950; Peterson, 1952), and the Dyna-Fog generator (McDuffie *et al.*, 1950; Yeomans, 1950).

Determinations were made of the droplet spectra produced with oil solutions of DDT emitted at various rates; the droplet spectra at various distances downwind; the portions of the clouds that were deposited on the ground; the amount of DDT that reached various distances downwind both in the open and in the woods; and the percentage reduction in landing rates of *Aedes* mosquitoes obtained in woodland for distances up to 400 yd. downwind.

MATERIALS: The following 5 machines were tested: 1. The Microsol Mechanical Aerosol Generator, Agricultural Unit Model 403, Silver Creek Precision Corporation, Silver Creek, N. Y. (Fig. 1). The insecticide is mechanically atomized by being thrown off the periphery of a sheaf of twenty-one 8.5-in. discs rotating at 8125 to 9750 r.p.m. Power is supplied by a 7½-h.p. Wisconsin engine, with a gasoline consumption of 0.6 g.p.h. at 3000 r.p.m. The weight of the complete unit is 442 lb. empty.

2. The Husman Pneumatic Fine-atomizing Sprayer, made by C. N. Husman, U. S. Bureau of Entomology, Orlando, Fla. (Fig. 2). The insecticide is atom-

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[4] See article by C. N. Husman, page 134, this issue of *Mosquito News*.—Ed. Note.