constructed by the Anchor Boat Company. The boat, motor and trailer complete cost approximately two thousand dollars.

The boat can be operated in the field by one man. It will carry several men and their equipment over marshes, meadows and mud flats covered with but a few inches of water or in deeper open water covered with aquatic plants. The boat is capable of speeds up to 35 miles an hour in all types of environment from wet mud slick to deep water. At slow speed in deep water the draught is approximately 3 inches whereas at high speeds the boat planes. The only undesirable features detected to date in this equipment are the difficulties experienced in steering the craft in high cross winds and the overheating of the air cooled motor after prolonged runs at higher speeds. These are obviously only minor difficulties but should be considered along with the advantages made possible by using an air propelled boat.

The use of an air propelled boat in Utah has made it possible to inspect repeatedly and with ease during 1955 areas on marshes and mud flats that were previously inaccessible (Fig. 1). Boats of this type have apparently become standard equipment for certain districts in Utah and will take the place of motor vehicles previously used, often unsuccessfully, in attempts to reach the prolific mosquito producing areas near the shores of the Great Salt Lake.

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REVIEW OF RECENT PROGRESS IN MOSQUITO STUDIES IN CANADA [1]

C. R. TWINN [2]

INTRODUCTION. During the past eight years considerable attention has been given to the study of mosquitoes and other biting flies in Canada. Much of this work has been performed on behalf of the Defence Research Board, Canada Department of National Defence, but recently the needs of the pulp and paper industry have also been given special attention. Many of the results have general application. Numerous papers based on these studies have been published since 1948; summarizing statements and references have been presented by Twinn (1950, 1952, and in press) and Freeman (in press).

This paper reports progress in the studies relating especially to mosquitoes and includes references to recently published and some unpublished work.

SYSTEMATICS AND DISTRIBUTION. In a review of some of the more important mosquito problems in Canada, Twinn (1949) presented a summary of the recorded distribution in Canada of 59 species of mosquitoes belonging to eight genera. Since then, several additional species (*Aedes hexodontus* Dyar, *A. implicatus* Vock. (=*A. impiger* of American authors), *A. rempeli* Vock., *A. pseudodiantaeus* Smith) have been found and many new distribution records obtained. This is largely the result of the Northern Insect Survey, carried out during the summer seasons of the past eight years by the Systematic Entomology Unit, Entomology

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Division, Ottawa, on behalf of the Defence Research Board. Specimens of biting flies and of many other insect groups were obtained from more than 50 Arctic and Subarctic localities.

An interim report on the distribution of the mosquitoes obtained in the Survey was prepared by Freeman (1952). In a brief account of the Survey, Freeman (in press) stated that data from these northern areas indicate that emergence of adult mosquitoes apparently commences about four weeks after the mean temperature for 14 days reaches 34° F., and that mosquitoes have not been found north of the July isotherm of 35° F.

Other useful sources of Canadian distribution records as well as of other biological information are papers by Haufe (1952), Curtis (1953), Twinn (1953), Rempel (1950, 1953), Judd (1954), and Vockeroth (1954b). Of the two papers by Rempel, one (1950) deals with the mosquito larvae of Western Canada and the other (1953) with the adult mosquitoes of Saskatchewan. Both contain keys to the genera and species and excellent illustrations of the taxonomic characters used in identification.

Other important contributions to the systematics of Canadian mosquitoes are contained in three papers by Vockeroth (1950, 1954a, 1954b). In the first he reports specific characters in the tarsal claws of some species of *Aedes;* in the second he describes two new species of this genus and clarifies the identities of certain others, and in the third includes a revised key to the females of northern species of *Aedes* and an outline of the distribution of each.

Beckel (1954a) discussed the difficulty of separating the females of the black-legged species complex within the *Aedes* genus in the Churchill region, and indicated the unreliability of the mesonotal colour pattern for this purpose. He suggested characters that may be used to separate all the species in the complex (except *A. punctor* (Kby.) from *A. hexodontus* Dyar, and *A. intrudens* Dyar from *communis* (Deg.)) and presented a key to the species based on these characters.

OTHER BIOLOGICAL STUDIES. 1. Laboratory Colonization. The study of mosquitoes and the development of more effective control and protective methods is facilitated if continuous laboratory colonies can be maintained. So far, it has not been possible to do this with northern species of *Aedes,* but the subject is receiving special study by Mr. W. E. Beckel, Defence Research Northern Laboratory, Fort Churchill, Man. The more important problems under investigation include breaking the diapause in the eggs and stimulating them to hatch whenever required, determining optimum conditions for rearing the larvae and pupae, and inducing the adults to mate and lay viable eggs in cages. Although success in colonizing any of these species has not yet been achieved, valuable progress toward this end has been made, and as the study involves an investigation of all stages of the life-cycles of the insects, it has produced much useful biological information (Beckel, 1953, 1954b).

2. Environment, Behavior, and Development. A study of the physical environment and behavior of the immature stages of *Aedes communis* (Deg.) made over a period of three years in selected pools in open subarctic forest at Churchill, Man., has been reported by Haufe (in preparation). He showed that behavior patterns of this species modify the effect of environmental conditions on rate of development, and that these behavior patterns are related to conditions in the pools caused by factors peculiar to far northern latitudes, such as the underlying permafrost and the low angle of inclination to the horizontal of the sun.

Haufe points out that the relations thus established between mosquito development and environmental conditions in this northern area are different from those reported from tropical areas. In the north the behavior of immature stages of mosquitoes is such that solar radiation has an important effect on the rate of development.

This is because mosquitoes in the north generally develop under suboptimum temerature conditions, and consequently the larvae and pupae insolate themselves at the surface of the pool to raise the body temperature above the ambient temperature; furthermore, peripheral insolation in the pools provides horizontal as well as vertical temperature gradients, which influence both the development and the behavior of the larvae and pupae.

From these observations on the behavior and development of *A. communis* and associated species, and mathematical descriptions derived for the relation between meteorological elements and the daily average temperature of mosquito pools, Haufe and Burgess (in press) suggested formulae for predicting mosquito emergence in a permafrost, forest-tundra transition area. They also stressed the need of further research to establish the applicability of these formulae to temperate regions and to areas of more varied topography than exist at Churchill. A summary of the principles involved has been published (Haufe, 1953).

3. Mosquito Behavior and Weather. Projects were also completed at Churchill on the relation between the activities of adult mosquitoes and meteorological conditions. The voluminous data from this three-year study are still being organized and statistically analyzed. Mr. W. O. Haufe, who was the leader in these projects and is now in charge of the Livestock Insect Section, Science Service Laboratory, Lethbridge, Alta., proposes to publish the results in a series of three papers under the general title "Mosquito Behavior and Weather": the first on the relations of macrometeorological factors to adult mosquito behavior, the second on relations of the ecoclimatic environment to mosquito activity, and the third on relations of mosquito activity to the human host under natural microclimatic conditions.

A related study on the vertical distribution of *Aedes* mosquitoes was started at Churchill in 1953 and continued at Rowanton Depot, Que., in 1954, to augment the data obtained at ground level. Knowledge on this subject is necessary for a more thorough understanding of mosquito behavior and to make possible more effective and economical use of insecticides in control operations. Sampling techniques have to be developed and the efficiency of sampling devices measured.

An index to mosquito flight activity at ground level was obtained by means of an hourly sampling, visual attraction trap. Essentially the trap consists of a revolving metal cylinder painted with alternating black and white stripes and suspended from a tripod. Statistical analysis of catches over a period of two or three years is required to determine its variability in efficiency of attraction. However, an assessment of the efficiency of this trap in comparison with a suction trap in the forest at Rowanton Depot, Que., in 1954, by Mr. L. Burgess (unpublished data) gave results indicating that the visual attraction trap does not give an accurate picture of the species composition or relative abundance of species in a mosquito population.

Methods of obtaining samples of mosquitoes at different altitudes tried at Churchill included the use of sweep nets on light aircraft, and attached to box kites towed behind a railway speeder on the Hudson Bay Railway. Neither method proved satisfactory. Perhaps electrically operated visual attraction traps placed on towers at various heights might be more effective.

The effect of atmospheric pressure on the flight activity of mosquitoes was also studied by Haufe (1954) in laboratory experiments at the University of Western Ontario, London, Ont., with *Aedes aegypti* (L.). Females with similar development histories, namely, those emerging from the same brood within 8-hour periods of relatively stable pressure, were used in all the experiments. He found that changes in atmospheric pressure are an important factor in determining flight activity, provided that the mosquitoes are first acclimated for 3 to 6 hours to a particular pressure level. When the pressure was above 735 mm., decreasing pressure was more stimulating to flight than increasing pressure, whereas when it was below 735 mm. the opposite was obtained. At 500 to 550 mm. the effects of changing pressure were negligible.

4. Dispersal and Flight Range. In planning control measures, it is important to have knowledge of the dispersal habits and flight ranges of the various species. Toward this end, Shemanchuk *et al.* (1953), with prairie mosquitoes in Saskatchewan, developed an improved method of radioactive tagging. This consists of keeping fourth-instar larvae in a solution of 0.1 microcuries of radioactive phosphorus (P^{32}) per millilitre of water for 24 hr. at a density of one larva per millilitre and returning the larvae to their normal habitat to complete their development. In an experiment with *Aedes flavescens* (Muller), radioactive females were collected as far as 6.6 miles from the emergence site and males 1,400 yards (Shemanchuk *et al.*, 1955). However, the value of this method is limited, because the population of tagged mosquitoes is rapidly diluted as it moves away from the emergence site, so that collection of tagged specimens becomes progressively more difficult and uncertain the farther it is done from the site. To obtain evidence on the outer limits of flight range especially of prairie and tundra species requires the tagging of enormous numbers of larvae and the use of more efficient collecting and trapping methods than are at present available.

Hocking (1953) followed a different approach to the problem of flight range by studying the energy resources of some of the northern species at Churchill in relation to their power requirements and efficiency in utilizing energy in flight. By ingenious observations and experiments, he obtained data on which he based estimates of the maximum distances certain species might travel in still air and their possible maximum air speeds. He concluded that the northern biting flies, including mosquitoes, obtain their energy for flight from the nectar of flowers, and that peaks of nectar production on tundra and in forest coincide with the peaks of flight of tundra and forest mosquitoes. Significantly, the crops of female mosquitoes swarming were found to be full of nectar. He made the novel suggestion that if honey bees were introduced in adequate numbers in the Churchill region they would provide strong competition for the available supplies of nectar, and might thus restrict the flight range of migratory species of mosquitoes and greatly reduce the area it would be necessary to treat with an aerial spray to obtain local control.

Another approach to this problem has been followed by Mr. J. A. Downes, Veterinary and Medical Entomology Unit, Ottawa, in a project on the flight characteristics of *Aedes* mosquitoes in relation to swarming, distribution, and finding of hosts. Observations on the swarming habits of mosquitoes at Churchill in 1952 and 1953 indicate that the insects orient themselves upwind while in visual contact with the ground. During temperature inversions, they follow the warm air upward and, in treeless country, lose contact with the ground and move downwind. Convection currents may also carry them to a height where they lose visual contact with the ground and fly with the wind. This is a possible explanation of the mass movement of mosquitoes for long distances over prairie and tundra. Downes (1955) has reported the results of similar studies with biting midges (*Culicoides* spp.) that show many parallels with the mosquitoes.

Hocking (1953) summarized published information on the flight ranges of 41 species of mosquitoes. The farthest distance he recorded was about 110 miles by *Aedes sollicitans* (Wlk.) over the sea.

5. Food and Egg Development. Earlier studies in Canada to determine the foods of adult mosquitoes and other biting flies have been reviewed (Twinn, 1952). Mr. A. E. R. Downe, Veterinary and Medical Entomology Unit, Ottawa, is continuing work commenced at Queen's University, Kingston, Ont., by West and Eligh (1952) on the determination by

serological methods of the source and volume of blood meals of these insects. Specimens are trapped in barns and other buildings or netted in the field and those found to be engorged are smeared on filter paper or pinned with appropriate data and later subjected to the precipitin test, to determine upon which animal they have fed. The pinned specimens enable identifications to be made before the insects are destroyed in the tests.

Downes (in preparation) points out that there is a sexual difference in the food habits of biting flies in the families of Nematocera (mosquitoes, blackflies, punkies, moth flies) and lower Brachycera (horse flies, deer flies, snipe flies). Both sexes take carbohydrates, usually as nectar from flowers, for energy, but the females also take protein, as in blood meals, for use in egg production. He states that this generalization applies to all the families of biting flies in these groups, equally to the well-known forms such as mosquitoes and blackflies, which feed on the blood of vertebrates, and to the net-winged midges (Blepharoceridae) and many species of punkies, which obtain their protein from the blood of other insects, or, as in one species of the latter, from the contents of pollen grains of honeysuckle. In a few species the eggs are developed from reserves laid down in the larval stage and retained in the fat-body or muscles.

Hocking (1954) concluded from a study of field-collected females that the form of *A. communis* prevalent at Churchill, Man., utilizes the nitrogen from autolysis of the flight muscles in developing its eggs. Beckel (1954c), who found that *A. communis* at Churchill did not take or need a blood meal to develop eggs, reported that females reared in the laboratory from field-collected pupae developed and laid eggs on a diet of sucrose or raisins alone, without any indication of reduction or abnormality of the flight muscles. He suggested the fat-body and larval muscles in the adult as other possible sources of protein for egg development in this species.

6. Behavior in Relation to Hosts. Information on the behavior of mosquitoes in relation to their hosts is of value in developing methods of personal protection. During recent years, Brown (1952) and others have investigated the responses of female *Aedes* mosquitoes and published a series of papers on the results. The most recent paper (Smart and Brown, in press) reports the effects of skin temperature, hue, and moisture on the attractiveness of the human hand as demonstrated in laboratory experiments with *A. aegypti* at London, Ont. Dark skins were found to be more attractive than light skins: negroes more attractive than orientals, and both more attractive than caucasians; of the last, dark-skinned individuals were more attractive than light-skinned. With caucasian subjects, warm skins were more attractive than cool skins. Hands artificially cooled to 72 to 77° F. were only one-fourth as attractive as normal hands at 88 to 93° F. Hands of individuals with low moisture output were more attractive than those of high moisture output. Hands induced to perspire freely were less attractive than the normal hand. Laboratory tests were also made of the attractiveness of human sweat to *A. aegypti*. From these, Thompson and Brown (1955) concluded that sweat from the armpits of caucasian males was significantly attractive, but sweat from the foreheads was not.

In a recent paper Brown (1954a) reported on the attractiveness of colored cloths to species of *Aedes* in Canada. Eight dyed flannels, seven colored satins, and 17 other fabrics were tested. Their attractiveness varied inversely with their brightness or reflectivity of visible light in the wavelength range of 475 to 625 millimicrons; for color values of similar lightness or darkness, the order of attractiveness was black, red, blue, green, white, and yellow. Field tests at Goose Bay, Labrador, showed that the wearing of clothing unattractive to mosquitoes does not increase the number of attacks by the insects on the unprotected skin of the wearer (Brown, 1955).

Dr. A. A. Kingscote, Ontario Veterinary College, Guelph, Ont., is also carrying out experiments to obtain information on factors that attract or repel mosquitoes. A completed investigation (Kingscote, 1954) indicated that the surface temperature of the host had a definite effect on the attractiveness of rats to *A. aegypti.* Age of the host in itself had a negligible effect, and weight had an inverse relation to the number of mosquitoes attracted. Atmospheric pressure influenced the number attracted under the conditions described.

Biological Control. The role of parasites and predators in the natural control of mosquitoes and other biting flies is being studied by officers of the Entomology Laboratory, Belleville, Ont. (James, 1953).

The life-history of a nematode, *Limnomermis* sp., parasitic in larvae of *Aedes communis* (Deg.) was ascertained in general at Churchill, Man., and some data were obtained on the life-history of a protozoan, *Thelohania legeri,* also a parasite in the larvae of this species. James (in preparation) also studied a chaoborine predator, *Mochlonyx culiciformis* (Deg.), in woodland pools at Chatterton, Ont. He found that it has one generation a year and a life-history apparently similar to those of the *Aedes* species associated with it. Its larval food consisted mainly of small crustacea and it preyed on mosquito larvae only when these were smaller than itself. The role of other predators of mosquito larvae, including several species of aquatic beetles, is under study. Progress in the use of the precipitin test for determining predator-prey relationships has been reported by Hall *et al.* (1953) from studies carried out in the Department of Biology, Queen's University, Kingston, Ont.

Natural enemies are probably of prime importance in reducing mosquito populations, but much more needs to be known about them and their role in mosquito control before it would be practical to attempt to increase their effectiveness on a sufficiently large scale to be of value.

Chemical Control. 1. Control Work in Canada. Mosquito control work in Canada is generally carried out on a modest scale. The Royal Canadian Air Force and the Canadian Army provide protection for their larger military establishments and some of the smaller isolated ones by aerial spraying of surrounding areas of up to 10 sq. mi. or more with DDT larvicides and adulticides. These treatments are supplemented by conventional ground measures and methods of personal protection. Mosquito control is also practised in some of the national parks by the federal government to protect visitors. Many towns and smaller communities as well as the larger cities across Canada take local action against mosquitoes when these are troublesome in their environs, but annual expenditures rarely exceed a few thousand dollars in any one area.

An example is Winnipeg, where anti-mosquito work has been carried on since 1927, until recently with wholly inadequate funds. Of the approximately 23 species identified in the area, a number are typical prairie forms that may disperse considerable distances. Stansfield (1953) has given an interesting account of the development of the control work in this area since its inception. The situation at Winnipeg was much improved in 1954, when, on March 25, the Legislative Assembly of Manitoba passed "An Act to provide for the establishment, powers, and duties of the Greater Winnipeg Mosquito Abatement District," the first of its kind in Canada. One immediate benefit from this legislation was an increase in the annual appropriation for mosquito control from about $12,000 to nearly $35,000 that resulted from a levy of 10 cents per capita in Greater Winnipeg.

Experimental work in the chemical control of mosquitoes and other biting flies has been carried on by the Veterinary and Medical Entomology Unit, Ottawa, with the cooperation of the National Defence Department and other agencies, including, recently, the Pulp and Paper Research Institute of Canada (Peterson, 1955).

An account of the development of methods of controlling mosquitoes with insecticides and the testing of machines for applying them in Canada was presented by Brown (1954b). Control recommendations were described by Twinn and Peterson (1955).

Area control by applying DDT from aircraft is reasonably effective south of the tree line when properly applied over a sufficiently large area, the size of the area depending largely on local conditions, such as species, topography, and vegetation. It is not practicable on the tundra because the prevalent species of mosquitoes may travel long distances and quickly reinfest treated localities.

2. Resistance Studies. A year or two ago unsatisfactory results from the application of aerial sprays in southern Ontario were blamed on resistance of mosquitoes to DDT. However, standard laboratory tests of larvae and adults from various localities in the region indicated that there was no perceptible difference in susceptibility between mosquitoes from areas where DDT had been sprayed in previous years and those from unsprayed areas (Brown *et al.*, 1954).

3. Aerial Spraying. Much valuable work on the investigation and development of insecticide dispersal equipment on aircraft, the assessment of aerial sprays, and the development and testing of insecticide formulations has been carried out at the Defence Research Board's Suffield Experimental Station, Ralston, Alta., under the direction of Dr. H. Hurtig, of the Entomology Division, Canada Department of Agriculture. Hurtig (1953) has published a brief review of the development of the use of aircraft for applying insecticides, and has a complete review of the airspray work at Suffield in preparation.

During the past four years officers of the Veterinary and Medical Entomology Unit, Ottawa, have assessed the performances of a number of machines in producing aerosols and controlling adult mosquitoes. Five of these, namely, the Microsol, the Husman, the Bes-Kil, the TIFA, and the Dyna-Fog, with emission rates of 20 g.p.h. or more, were tested in 1951 and 1952, and the results published (Brown and Watson, 1953). Two portable generators with lower emission rates, namely, the Swingfog and the Dyna-Fog Jr., were tested in a similar manner in 1953 and 1954 (Brown and Morrison, 1955).

A portable mist sprayer operated on the pneumatic principle at a pressure of 10 p.s.i. has been designed at Kamloops, B. C., by Curtis (1954). It is power-driven by a light gasoline motor and air compressor, and equipped with a tank of 2 gal. (imp.) capacity. It weighs 40 lb. when empty and 58 lb. when fully loaded, and is intended for use in hilly and wooded areas where roads and trails passable to vehicles are lacking.

In July, 1954, Dr. A. W. A. Brown, University of Western Ontario, who has taken an active part in biting-fly investigations while in the seasonal employ of the Entomology Division, assisted in tests of various machines for applying adulticides in the San Joaquin Valley, California, carried out as a joint study of the California Mosquito Control Association and the California State Department of Health's Bureau of Vector Control. The results (Brown and Mulhern, 1954), although not conclusive, should lead to the more effective use of adulticides and encourage further studies of a similar nature.

REPELLENTS. At the Ontario Veterinary College, Guelph, Ont., Kingscote (1952) demonstrated experimentally that laboratory animals developed no repellent action against *A. aegypti* from the internal administration of tolerable doses of known insect repellents, alcohols, aldehydes, ethers, esters, acids, amides, phenols, saturated aliphatic hydrocarbons, aromatic hydrocarbons, alkaloids, ketones, oleo resins, salts, volatile oils, vitamins, sex and other hormones, and body deodorants.

In studies of repellents at Toronto and Ottawa, Ont., there has been little progress beyond that reported by Roadhouse (1953) and Kasman *et al.* (1953). Existing techniques for the laboratory assessment of repellent compounds have proved unsatisfactory because of a high degree of variation in the results obtained, which makes them difficult to interpret. This is believed to be due to variation in (1) the rates of absorption of the chemicals in different subjects, (2) in volatilization, and (3) in the responses of the test insects. Attempts are being made by Mr. D. G. Peterson, Veterinary and Medical Entomology Unit, Ottawa, to develop a more suitable technique for measuring quantitatively the inherent repellency of such compounds.

SUMMARY. Progress in studies on mosquitoes in a biting-fly research program in Canada is reviewed and references are given to recently published and some unpublished work. The subjects dealt with include systematics and distribution of Canadian species; attempts to rear laboratory colonies of northern species of *Aedes;* relation of the immature stages to their environment; behavior of adult mosquitoes in relation to meteorological conditions; their dispersal and flight range; food of the adults; responses of *Aedes* females to various factors relating to their hosts; biological and chemical control, and repellents.

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See pages 237–240 for information on the AMCA meeting in Beaumont, Texas, in February.