

CONTROL OF ADULT MOSQUITOES AND BLACK FLIES BY DDT SPRAYS APPLIED FROM AIRCRAFT¹

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It has already been demonstrated in various parts of subarctic Canada that the aerial spraying of mosquito breeding areas with DDT at 0.25 pound per acre kills, on the average, approximately 90 per cent of the *Aedes* larvae present (Twinn, Brown, and Hurtig, 1950). However, the effect of such treatment of areas of 5 and 17 sq. mi. was to reduce the adult mosquito population throughout the remainder of the season only to approximately one-half of that in unsprayed areas. A large-scale experiment was performed at Goose Bay, Labrador, in 1950, to ascertain the effect of a single aerial spraying applied to kill adult mosquitoes shortly before they attained their maximum numbers. The effect of this spraying on adult black flies was also observed.

THE LOCALE AND THE MOSQUITO SPECIES

At Goose Bay, Labrador (lat. 60° S, long. 53° N), the air base is occupied by both Canadian and American personnel. It is situated on a sandy plateau covered with lichens and scattered, small black spruce. Eastward and southward it drops 100 ft. to a plain bordering Terrington Basin and the Hamilton River, and bear-

ing a relatively dense forest of spruce with admixed birch, willow, and alder. This area was included with the plateau in the sprayed area. East and north of the sprayed area are extensive sphagnum bogs, and to the west the ground rises in rocky hills clothed with spruce. Few mosquitoes breed on the sandy plateau, but the bogs and numerous forest pools in the surrounding low-lying areas are a major source of infestation.

The predominant species were *Aedes punctor* (Kby.), *A. implacabilis* (Wlk.), *A. communis* (DeG.), and *A. pionips* Dyar. These black-legged forest species cannot readily be distinguished from one another in the female form, but they were abundant in the larval stage, and probably comprised the great majority of the mosquitoes attacking man. Other species, in smaller numbers, included *A. fitchii* (F. and Y.), *A. canadensis* (Theo.), *A. cinereus* Meig., and *A. diantaeus* H., D., and K. Overwintering females of *Culiseta impatiens* (Wlk.), *C. alaskaensis* (Ludl.), and *Anopheles earlei* Vargas, although present in moderate numbers earlier, were scarce or absent by the time the spray was applied.

THE AERIAL SPRAY AND ITS APPLICATION

With the aid of available maps, an area of 19 sq. mi. around the air base was delimited, and marker points for the aircraft tracks were placed at 200-yd. intervals along roads selected as base lines. The area was divided into eight large sections, each measuring slightly more than two square miles, and two smaller, intercalated sections (Fig. 1).

Two spraying flights were made each night, and each flight covered two square miles. The line of flight for each track of spray was indicated by a luminescent marker that served as the starting point, and by the magnetic heading on which

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the pilot of the aircraft was instructed to fly; the length of the track determined the number of seconds of flight that the spray valve was to be open. As the speed of the aircraft was 140 m.p.h., a swath one mile long was covered in 25.8 sec. The height at which the aircraft was to fly was governed by the speed of the crosswind component of the wind prevailing at the time. The height-wind products (Twin, Brown, and Hurtig, 1950) selected were, on the average, between 1,000 and 1,500 ft.-mi./hr. The wind speeds were obtained by radio from the control tower of the airfield, and heights were relayed to the aircraft from the ground by wireless. All operations were performed under conditions of zero

temperature gradient; this was checked at a mobile meteorological station consisting of two shield thermo-couples attached to a staff at heights of one metre and two metres, and connected with a galvanometer (Fig. 3). Spraying was commenced between 1900 and 1950 hr., and finished between 2050 and 2200 hr.

The aircraft employed was an R.C.A.F. Dakota Mark I (C-47) used for search and rescue duties on the station. It was fitted with a temporary installation consisting of two auxiliary fuel tanks designed for the Mitchell (B-25) aircraft. This could be installed by four men in three and a half hours. The spray solution was led to a vertical emission pipe by means of 4-in.

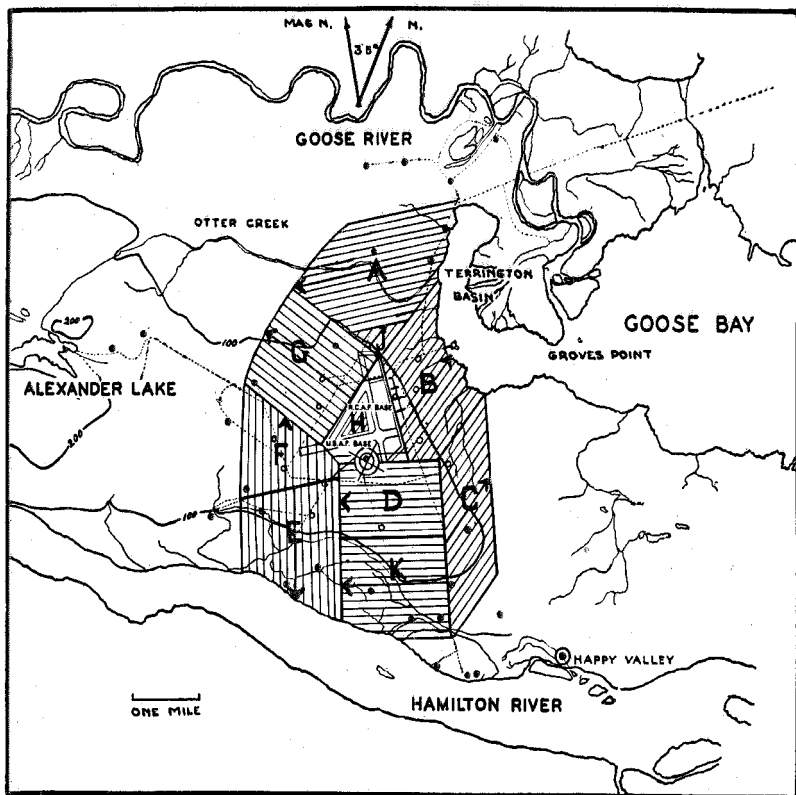


FIG. 1. Map of Goose Bay showing location of 10 plots sprayed with DDT. Fine lines indicate lines of flight of aircraft; arrows, the direction of flight; black dots, the locations of biological assessment points inside and outside the sprayed area.

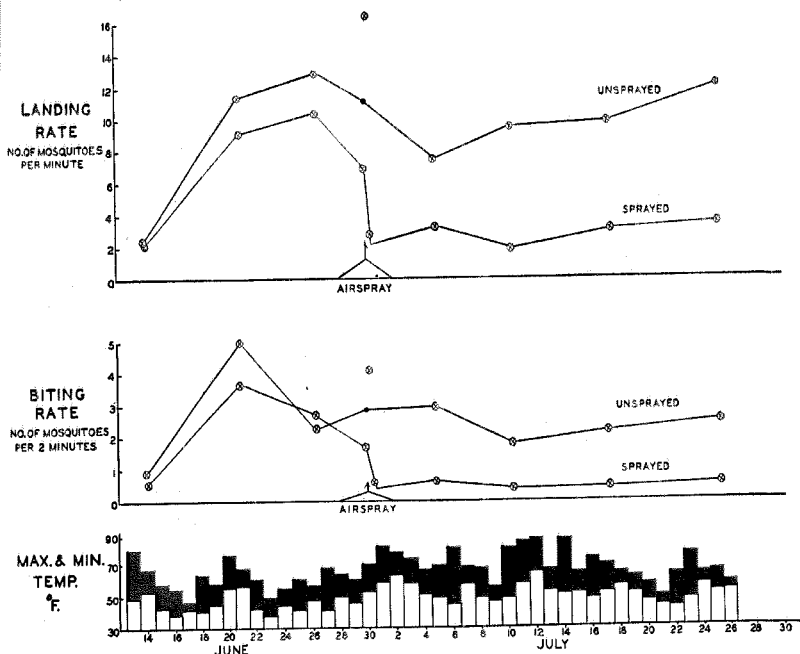


FIG. 2. Landing rates and biting rates of mosquitoes in sprayed and unsprayed areas, and daily maximum and minimum temperatures, June 13-July 26, 1950, Goose Bay, Labrador. The landing and biting rates obtained for the unsprayed areas during the airspray operation, and plotted above as the figures for June 30 were unusually high, as they were taken at dusk, whereas all other assessments were made during the day; therefore the lines are drawn through a point representing two-thirds of their numerical value.

aluminum ducts attached to the sumps of the tanks (Fig. 4). A full load of spray contained 600 imperial gallons.

A quick-acting gate valve of special design led to an emission pipe extending vertically downwards through the floor and the fuselage skin. To the skin was affixed an emission device provided with an air scoop (Fig. 5). This consisted of a vertical section 2.5 in. in diameter and 18 in. long, tapered to 2 in. in diameter and affixed to a 2-in. elbow that directed its aperture rearwards; on the end of this 2-in. elbow there was a 5-in. length of 2-in. pipe, perforated by 28 holes, each three-eighths of an inch in diameter, and the end tapered into a cone perforated with 4 one-quarter-inch holes. This pipe was enclosed in an air scoop, with the for-

ward opening 6 in. in diameter and tapered over a length of 7 in. to a throat 4 in. in diameter; this throat was 5 in. long, and completely enclosed the perforated section of the pipe, then widened over a 3-in. length to a rearward opening 6 in. in diameter. The cross-sectional area of the annulus around the perforated section through which the spray was emitted was one-third of the cross-sectional area of the entrance to the air scoop.

The emission rate of the spray solution through this device, by gravity feed alone, was 1.1 gal. per second. The arithmetic mean of the diameters of the droplets of oil spray from this device was 97 microns, and the mass median diameter was 400 microns. These figures were obtained from an assessment at 40 sampling points

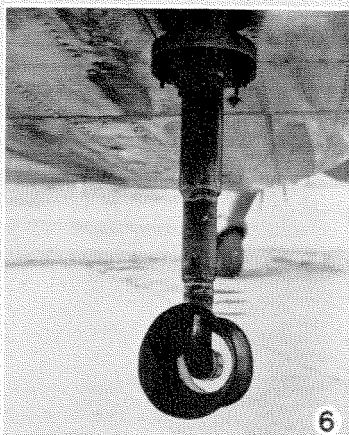
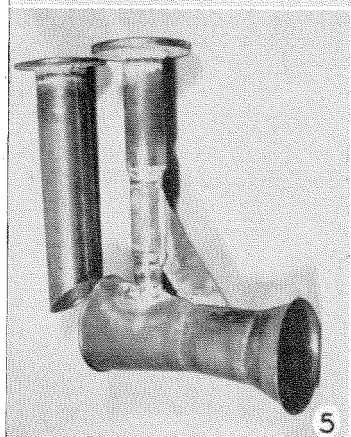
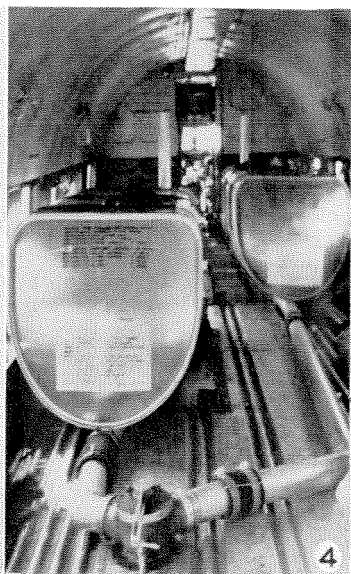
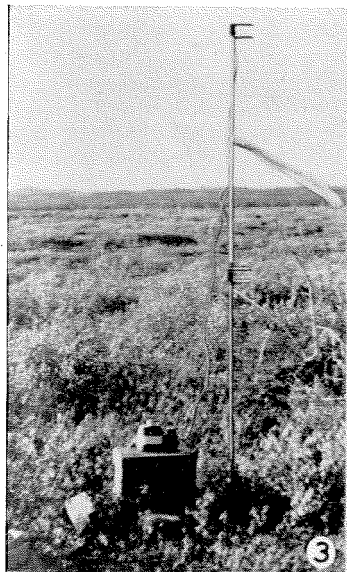


FIG. 3. Temperature gradient apparatus at field meteorological stations. FIG. 4. Spray installation in the fuselage of a Dakota aircraft. FIG. 5. Straight emission pipe and air-scoop modification. FIG. 6. Air-scoop device in place on underside of fuselage of aircraft.

at 10-yd. intervals downwind of the emission track of the aircraft, which was flown at a height of 200 ft. in a 5-m.p.h. cross-wind. At each point was placed a 4-in. petri dish containing a microscope slide (18.8 sq. cm.) coated with an oleophobic silicone (General Electric Drifilm 9987). The droplets of the spray, dyed with du-Pont oil red, were sized under a binocular microscope, with the Porton modification of the Pattison-Cawood graticule. The spread factor, or lens-droplet ratio, was determined by calibration with a small syringe to be 2.38. The droplet spectrum so obtained is shown in Table 1. The finer droplets in this spectrum were also sampled by means of impactors (Casella's model of K. R. May's design), fitted with silicone-coated slides and with an air intake of 10 litres per minute. Between 10 and 50 droplets, ranging between 5 and 30 microns in diameter, were obtained on the first slide, and no finer droplets were obtained on the succeeding three slides.

At the same time the droplet spectrum of the 2.5-inch straight emission pipe, used in the 1949 operations, was assessed. The figures in Table 2 show an arithmetic mean diameter of 79 microns and a mass median diameter of 340 microns. From this it is apparent that the air-scoop modification did not improve the performance of the straight emission pipe.

The spray solution consisted of a commercial DDT concentrate diluted with 5:7 parts of domestic fuel oil. The concentrate consisted of 25 per cent (wt./wt.) of DDT in Velsicol AR-60 (trimethylnaphthalene) solvent; hence each 45-gal. drum, weighing 500 pounds, contained 125 pounds of DDT. For each aircraft flight two drums of the concentrate were mixed with 510 gal. of fuel oil. This gave a 4.2 per cent (wt./vol.) solution of DDT in oil. The spray operations for each flight were so adjusted that the aircraft landed with from 12 to 100 gal. of spray solution in its tanks. The emission rate, as far as could be seen, remained almost constant throughout. The emitted dosage of DDT on each of the areas ranged between 0.151 and 0.187 pound per acre.

The outlying areas were treated first, and the operation terminated with the treatment of the Canadian camp itself. The average dosage emitted over the whole area was 0.165 pound per acre.

EFFECT OF AIRSPRAY ON MOSQUITOES

Forty sampling points were established throughout the area served by roads (Fig. 1). Landing rates and biting rates of mosquitoes and black flies were recorded usually by three observers working together. For mosquitoes, the landing rate was the number of mosquitoes landing on the front of the trousers between the waist and the knees and sideways to the seams during the third minute of observation; the biting rate was the number of mosquitoes biting the bared forearm between the wrist and the elbow during the third and fourth minutes of observation. Four pre-spray and five post-spray assessments were made in the area. The figures obtained on the mosquitoes (based on 120 observations for each assessment of the entire area) are plotted in Fig. 2.

Emergence of *Aedes* spp. commenced on June 1, and by June 14 they had become a nuisance about the camp buildings. By the third pre-spray assessment, June 26-27, the average landing rate in the central area had risen to 10.35, and in the outlying areas to 12.90 per minute, and the biting rates were 2.61 and 2.27, respectively. Personnel were being bitten in their sleeping quarters throughout the camp. Larval development was almost completed, except on the Hamilton River flats, where some pools still contained up to two larvae per dip.

The aerospray operation was commenced on June 28, and was completed on July 2.

The first post-spray assessments in the sprayed areas were made in the evenings, 24 hr. after each spray treatment, during the period June 29 to July 3. The average landing rate was 2.37 and the average biting rate 0.60. In the unsprayed, check areas the average landing and biting rates during approximately the same period (June 28-July 2) were 16.35 and 4.08. These results are plotted in Fig. 2 as the

TABLE 1. Droplet spectrum of spray from air-scoop emission device on Dakota C47. Numbers of droplets of various sizes deposited on coated slides exposed various distances downwind of emission track. Goose Bay, Labrador, 1950.

Droplet Diameter: (microns)	5	10	21	31	42	52	63	75	105	125	180	270	360	420	540	720
Yards Downwind																
50															0.9	
60															1	
70															2	1
80															2	1
90												4	3	4		
100												1	8	7		
110											1	2	1	1		
120											5	30	15	7		
130										8	59	28	1			
140								1	9	3						
150							1	3	2	5	6					
160				3	12	17	12	10	14	15	10					
170			3	8	19	23	26	15	18	10	3					
180			8	5	18	17	8	5	2							
190	2	4	5	10	8	2	5	8	2							
200		3	2	7	8	12	8	9	5							
210			6	12	37	28	13	6								
220	1	7	19	17	27	10	5									
230	1	1	3	18	15	9	11	1								
240			1	7	13	17	24	17	3							
250				1	6	10	22	9	10							
260			1	1	1	2	8	15	12							
270	1	-	-	3	3	6	6	1	2							
280		1	2	3	4	4	11	9	1							
290	1	-	-	3	5	3	10	2								
300					2	3	1	6	5	4						
310								1	4	11						
320				1	2	-	1	8	1							
330						1	5	2	1							
340					4	4	1	2	3							
350	2	2	1	-	1	3	2	1								
360			3	-	1	-	-	3								
370			1	-	1	3	-	1								
380					1	1	3									
390			1	2	2											
400					1	2										
Totals	2	13	41	76	169	201	168	186	118	72	84	65	28	23	3.9	1

TABLE 2. Droplet spectrum of spray from straight emission pipe on a Dakota C47. Numbers of droplets of various sizes deposited on coated slides exposed various distances downwind of emission track. Goose Bay, Labrador, 1950.

Droplet Diameter: (microns)	5	10	21	31	42	52	63	75	105	125	180	270	360	420	540
Yards Downwind															
90															
100								1	-	-	4	-	1	1	10
110									1	3	18	49	17	8	
120									2	10	92	78	8		
130					2	3	3	2	11	24	40	19	1		
140						6	14	36	58	82	54	10			
150				2	2	8	14	24	38	60	78	10			
160			3	16	28	34	26	24	27	22	6				
170		4	10	42	65	49	5	6	2						
180		5	34	35	26	27	16	9	14	2					
190		6	14	36	40	46	40	26	18	2					
200		6	26	45	45	31	19	5	3	2	6				
210				14	16	48	10	24	20	8					
220			2	17	13	15	4	7	3	3					
230				7	10	10	8	3	2						
240		1	3	5	9	14	16	13	7	2					
250		1	7	9	4	6	5	3							
260	2	3	5	6	4										
270			1	-	2										
280		2	20	20	20	32	17	10							
290		2	24	44	52	52	16	6	2						
300		7	21	24	49	42	11	7							
310		13	20	15	12	4	2	1							
320		6	12	13	6	2	2	1	1						
330		3	11	15	6	3									
340	2	4	4	12	10	10	3								
350		5	16	11	15	5	5	7	1						
360				4	9	6	5	2							
370			1	8	7	6	6	10	3						
380			2	4	9	7	3								
390			1	2	2	9	5	7							
400		1	3	3	3	8	5	2							
Totals	4	69	308	715	466	483	260	246	213	220	298	166	31	22	10

figures for June 30, but the lines are drawn through a point constituting two-thirds of their numerical values, to put them on an equivalent basis with the day-time counts used in all other assessments.

Population assessments in both sprayed and unsprayed areas were repeated on July 4-6, July 10-11, July 17-18, and July 25-26. The figures are plotted in Fig. 2. During the period covered by these assessments (July 4-26) the average landing rates in the unsprayed area ranged from 7.27 to 12.02 and the average biting rates from 1.70 to 2.87. Comparable average figures for the sprayed area were landing rates, 1.80 to 3.27, and biting rates, 0.27 to 0.61, approximately one-fourth and one-sixth, respectively, of those in the unsprayed area.

The differences between the pre-spray and post-spray results were tested by an analysis of variance applied to the figures obtained block by block, using the F distribution method. All of the differences were significant at the 5 per cent level, and half of them were significant at the 1 per cent level. The *p* values obtained for the comparisons were as follows:

	Landing Rates	Biting Rates
Fourth pre-spray vs. first post-spray	0.025	0.005
Third pre-spray vs. first post-spray	0.016	0.006
Third pre-spray vs. fifth post-spray	0.032	0.047

The final assessments, made on July 25 and 26, four weeks after the spray was applied, showed that the infestation in the treated area had not significantly increased. The average landing and biting rates in the sprayed area at this time were 3.24 and 0.50 as compared with 12.02 and 2.46 in the unsprayed area. If the final assessments for the sprayed area are grouped on the basis of central and peripheral areas, the average landing rate at the periphery is 6.29 as compared with 0.77 at the center. Furthermore, throughout the post-spray period the average landing rates at the center did not exceed 1.27. The biting rate in the central area at the last post-spray assessment was 0.21, slightly less than the rate of 0.31 obtained by the first post-spray assessment. The average figures for the peripheral points were increased

by the large mosquito population on the Hamilton River flats, which, by the end of July, was not noticeably different from that in adjacent unsprayed areas.

After the area was sprayed, mosquitoes were not seen on window screens in the camp, whereas four to eight per screen (and a maximum of 30) had been observed before the spraying. Mosquitoes first reappeared on screens on July 10, and the maximum number observed on any window screen between then and July 22 was six. Most screens remained free of them. The comparative absence of biting flies was favorably commented on by occupants of the base and by visitors.

As a result of the spray application, the outside doors of most of the buildings in the Canadian camp were left open, despite the absence of screen doors. This was encouraged by the excessive heating of the buildings, especially at nights. Mosquitoes eventually became a nuisance in the sleeping quarters on July 23 and 24, large numbers presumably being attracted by heat. They disappeared on July 25 and 26, after a period of heavy rain, when the quarters were not heated. Also, by July 23, the numbers of mosquitoes and black flies affecting children at play in the family housing area was causing some concern. As a very low biting rate is required to ensure the comfort of children at play, the camp and residential areas were again sprayed on July 28. This marked the termination of the main experiment.

Two smaller area spray experiments were performed, outside the area previously sprayed, to ascertain the effects of the treatment 1 hour and 14 hours after spraying. An area of 2.6 sq. mi. at Happy Valley, in the thick spruce forest on the Hamilton River flats, was treated at 0.15 pound of DDT per acre on July 15. The average landing rate dropped from 16.0 to 3.0 in the first hour, and to 2.2 in 14 hours; the average biting rate fell from 4.2 to 0.2 in the first hour, and increased slightly, to 0.5 in 14 hours. Hence, 14 hours after spraying, the landing rate was reduced by 86 per cent and the biting rate by 88 per cent.

A second assessment of the initial effect of the spray was made in open spruce forest near the Goose River on July 28. An area of 2.3 sq. mi. was sprayed at 0.16 pound of DDT per acre. Here the decreases in landing and biting rates were approximately 66 per cent in one hour and 98 and 87 per cent, respectively, in 14 hours.

EFFECT OF AIRSPRAY ON BLACK FLIES

The numbers of black flies in the Goose Bay area had been substantially reduced by the treatment of infested streams with DDT larvicide in June. This treatment had been applied to all streams known or believed to be infested with black fly larvae over an area of approximately 200 sq. mi. surrounding the air base. The details and results of this treatment will be presented elsewhere. Nevertheless, the insects became sufficiently abundant to be troublesome about the air base by the end of June. Two species, *Simulium venustum* Say and *Prosimulium hirtipes* Fries, appear to be mainly responsible for attacks on man in this region. During the large-scale spray operation of June 28-July 2, which was directed mainly against mosquitoes, adult black flies were observed to be quickly killed by the spray. In spite of this, the landing rate 24 hours after treatment was greater than before; this is attributed to rapid infiltration, since the second post-spray assessment indicated that the landing rate in the surrounding unsprayed area had increased considerably, and was over twice that in the sprayed area. This differential persisted during the third and fourth post-spray assessments, but at the last assessment, on July 25-26, it had almost disappeared. The black flies were most abundant near the Goose River, north of the base, on a dry sandy plain covered with slashed and burned spruce, where mosquitoes were few; on the other hand, black flies were few in deep woods near the Hamilton River south of the base, where mosquitoes were abundant.

Observations at Happy Valley on July 15 showed black fly landing rates of 1.4

before the spray, 1.3 immediately after the spray, and 0.4 the following morning. On this basis the reduction, 14 hours after treatment, was 71 per cent.

Observations in the Goose River area on July 28 showed a complete disappearance of black flies immediately after the spray, partially because of the failing light. The landing rate the following morning showed a decrease of 50 per cent as compared with the previous morning, and the number of adults taken by sweeping with nets had decreased by 71 per cent. The figure for the decrease might have been greater if the morning before had been as warm as the morning after.

Incidentally, the only creek that had not been treated with larvicide (Stream 145, Terrington Basin) was cleared of larvae, but not of pupae, by the aerospray.

ACKNOWLEDGMENTS

The Royal Canadian Air Force provided the aircraft, air and ground crews, spray material, transport, and certain other facilities used in carrying out this project. The authors wish to acknowledge with gratitude the essential part played in the aerial operations by Flight Lieutenants S. W. Yoder, D. R. Cuthbertson, and E. de Niverville. Acknowledgment is also made of assistance in the activities on the ground given by Flight Cadets G. C. Bending, H. T. Bonney, G. H. Hunter, and R. E. Paulette, of the R.C.A.F., and by J. S. Barton, G. T. Crosson, and J. J. Tibbles, of the Division of Entomology, Ottawa.

SUMMARY

To control adult mosquitoes an area of 18.7 sq. mi. at Goose Bay, Labrador, was sprayed between June 28 and July 2 with a 4.2 per cent DDT-fuel oil solution at an average dosage of 0.165 pound of DDT per acre by means of a Dakota C-47 aircraft fitted with a gravity-feed emission pipe modified with an air-scoop. Assessment of the sizes and distribution of the spray droplets showed that the air-scoop did not improve the performance of the straight emission pipe installation.

The initial effect of the spray on mosquitoes, mainly *Aedes* spp., was to reduce the landing rate by 86 per cent in dense forest and by 98 per cent in open forest. The long-term effect was to reduce the average landing rate from 9-10 to 2-3 per minute; four weeks after spraying the average landing rate in the sprayed area was 3.2 per minute as compared with 12 per minute in the unsprayed area. Average biting rates in the sprayed and unsprayed areas showed similar results.

The initial effect on black flies was to

reduce their landing rate by approximately 70 per cent, although results were highly variable. The landing rate in the sprayed area was approximately 50 per cent of that in the surrounding unsprayed area for two weeks after spraying, 60 per cent after three weeks, and 80 per cent after four weeks.

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RESEARCH ON MOSQUITOES BY THE BUREAU OF ENTOMOLOGY AND PLANT QUARANTINE DURING 1950

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This is a brief summary of the research on mosquitoes carried on by the Bureau of Entomology and Plant Quarantine during 1950. The information has been made available to me by Alan Stone, taxonomist in the Washington, D. C., office; A. W. Lindquist, in charge of the Corvallis, Oregon, Laboratory; W. V. King, in charge of the Orlando, Florida, laboratory; and R. C. Roark, of the Beltsville, Maryland, Agricultural Research Center. The taxonomic investigations and those conducted at Corvallis and at the Beltsville Agricultural Research Center are financed by regular appropriations from Congress, whereas those at Orlando are financed by funds allotted by the Department of Defense.

TAXONOMY

Work on the taxonomy of mosquitoes consisted almost exclusively in assisting outside research workers with the loan of specimens, providing notes on types and other specimens in the United States

National Museum, and giving aid to visiting workers. John Lane, from Brazil, spent nearly four months in Washington studying Neotropical mosquitoes. W. H. W. Komp and L. E. Rozeboom also spent some time in the Museum on various mosquito problems. Important loans were made to Walter J. LaCasse, P. F. Mattingly, R. M. Bohart, Robert Matheson, E. B. Thurman, R. F. Darsie, Jr., and W. B. Hull. The only important lot of mosquitoes sent in for determination was a fine collection of Iranian species from R. P. Dow. One paper, a description of the larva of *Culex foliaceus* Lane from the coast of Brazil, was published by Alan Stone.

INSECTICIDES

RESEARCH AT THE BELTSVILLE AGRICULTURAL RESEARCH CENTER

The recent development of allethrin—the so-called synthetic pyrethrum—by M. S. Schechter and F. B. La Forge is an