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THE EFFECTS OF DDT SPRAYED FROM THE AIR AGAINST LARVAL AND ADULT WEST AFRICAN MOSQUITOS

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THE EFFECTS OF DDT SPRAYED FROM THE AIR, AGAINST ADULT AND LARVAL WEST AFRICAN MOSQUITOS

Report on trials at Takoradi, Gold Coast, carried out from August-November, 1944, by a team consisting of:-

W/Comdr. A. J. Black	S.F.S.D. Porton. Officer commanding the Unit.
Prof. P. A. Buxton, F.R.S.	In charge of all entomological work.
S/Ldr. W. D. Phillips	Planning and Reporting Section, Porton.
S. H. Fryer	Head, Engineering Section, Porton. (Present July-Sept.).
B. A. Toms	Chemistry Section, Porton.
J. W. Siddorn	Physics Section, Porton.
E.S.M. J. Goldthorpe, R.A.	Field Trials Section, Porton. (Present Oct.-Nov.).
Sgt. S. J. Jackson, R.A.F.	Technical Chemistry Section, Porton.

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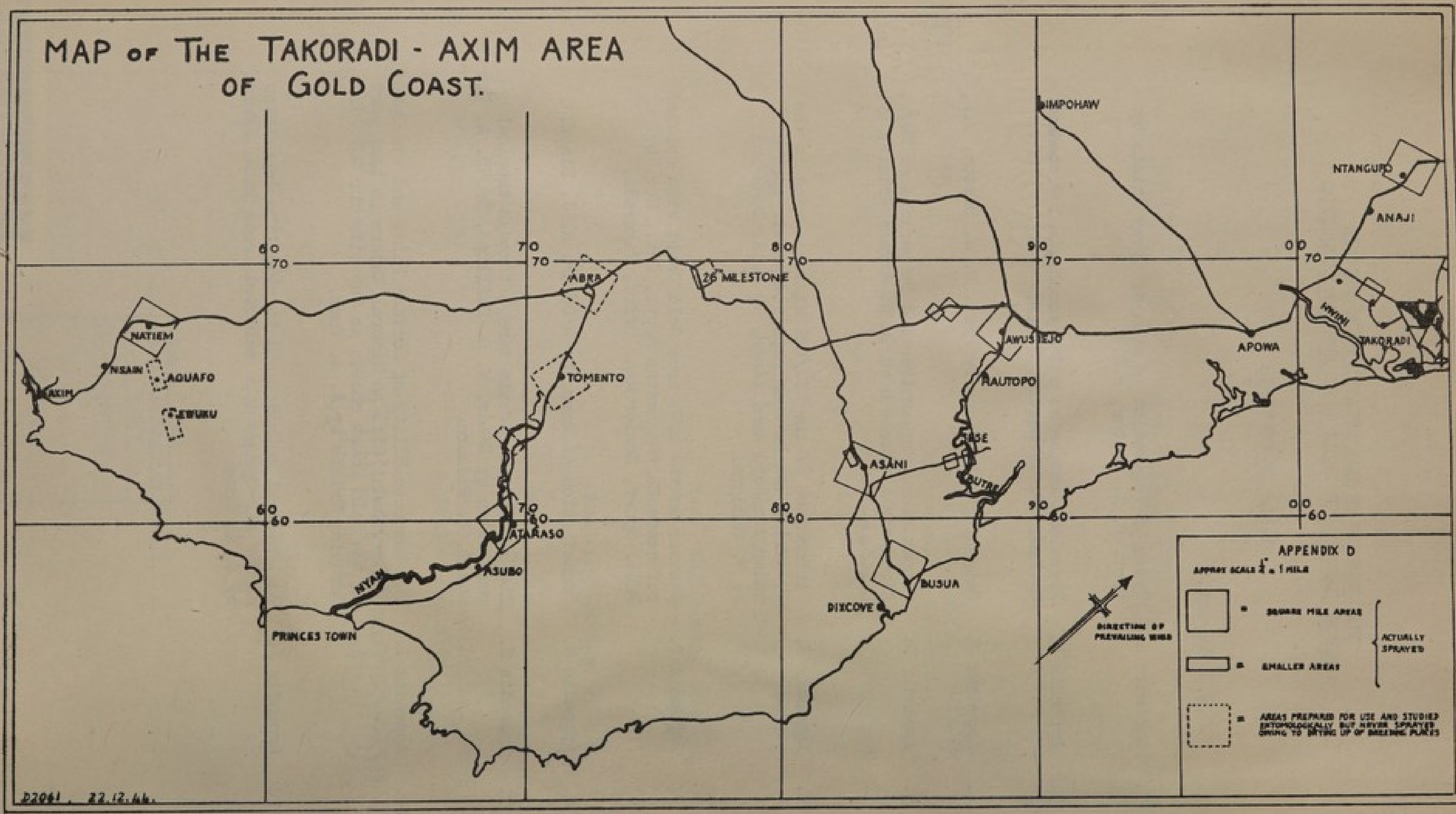
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THE EFFECTS OF DDT SPRAYED FROM THE AIR AGAINST LARVAL AND ADULT WEST AFRICAN MOSQUITOS

PREAMBLE

1. In P.R.2627 it was recommended that trials of DDT air sprays should be carried out against mosquitos in their natural habitat. This was agreed upon, and West Africa, being an accessible area of wet, tropical forest, was selected as the site for the trials. Accordingly, early in July, 1944, a team left Porton for Takoradi, on the Gold Coast. The necessary stores were forwarded by sea, and the Air Ministry arranged for a squadron of Vengeance Aircraft to fly from India. Professor P. A. Buxton, F.R.S. accompanied the Porton team to take charge of the entomological work.

2. It had originally been intended to commence work before the end of July, at which date there was a plentiful population both of A.gambiae and A.funestus breeding in the trials area. Unfortunately although both the entomologists and the Porton team were at Takoradi by that date and were ready to commence work, the stores did not arrive until August 16th and no aircraft appeared until August 25th, when two arrived. It was in fact September 15th before a sortie of five aircraft could be put into the air. This had a profound and far reaching effect on the whole experiment, since it extended the trials into the dry season, with a consequent serious diminution of the mosquito population.

3. It was intended (Ptn.1641 (U.6740)) that the trials in W. Africa should yield information concerning:-

(i) The larvicidal action of DDT air spray in breeding places screened by vegetation of different kinds.

(ii) The possibility of controlling populations of adult mosquitos by means of DDT air spray discharged in daylight over their natural habitat.

(iii) The comparison of oil solutions and oil-in-water emulsions as means of disseminating DDT for the purposes described in (i) and (ii).

4. In addition it was hoped to obtain information concerning:-

(i) The nature of air movements in tropical forest.

(ii) The spreading of drops of DDT air spray upon natural water surfaces.

(iii) The physical aspects of air spray penetration through vegetational cover of different kinds.

(iv) The effects of storing certain DDT concentrates under tropical conditions.

INTRODUCTION

Terrain - Vegetation

5. A coastal area was selected for the trials lying between Takoradi (4° 53' N. 1° 45' W) and Axim (4° 52' N. 2° 14' W) and extending about 15 miles inland. Except for a coastal strip about a mile wide, the country around Takoradi is undulating with many small hills none exceeding 300 feet high. Generally these hills were clad with secondary (occasionally primary) evergreen rain forest, the trees rising in some cases for another 150-180 feet, (the photos are attached at the end of the report). The broken ground and the presence of tall solitary trees considerably influenced the flying technique.

6. Throughout this report the names for different types of forest are those defined by Burtt Davy in "The Classification of Tropical Woody Vegetation types (University of Oxford, 1938)". The vegetation is dealt with in detail in a memorandum by Prof. Buxton at Appendix A.

7. At one time or another almost all the land in the area has been cleared for cultivation, so that but little primary rain forest remains. Much of the land however has reverted to secondary forest which is difficult to distinguish from, and is often denser than the primary bush. This reversion is gradual and intermediate stages show either an impenetrable mass of climbing herbs and yellow flowered sunflower (photo. 2), or areas of dense cover 15-30 feet high (photo. 3) consisting mainly of shrubs and small trees. More specialised areas are mangrove swamps (photo. 4), fresh-water swamp forests covered with spiny climbing palms (photo. 5), treeless swamps, usually sedge or fern covered and enormous bamboo clumps (photo. 6).

8. The cultivation itself is mainly cassava, maize (photo. 7) cocoa or palms. These apparently offer only light overhead cover, but in fact owing to the lateral drift of the air spray, they have a considerable filtration effect. (See photographs 8 and 9.)

Mosquito population

9. Prof. Buxton has described the prevalent anophelines in a separate memorandum, attached as Appendix B. Briefly, the main population is Anopheles funestus with a few A.gambiae. Owing to the late start of the trials enforced by the non-arrival of stores and aircraft, the latter had almost disappeared through the drying up of their wet season breeding places and the population of A.funestus was much diminished. Moreover the fact that the main population was A.funestus may have prejudiced the results achieved against larvae, since A.funestus normally selects a sheltered breeding place (see Photographs 10 and 11). The local Culicines seldom attacked man and were therefore only of value for judging any larvicidal effects.

Trial Areas

10. It was agreed that in order to study the effects of DDT air spray on the adult mosquito population; the area sprayed should be one mile square (so as to reduce infiltration of adults from outside the area during assessment). This, together with the fact that the area must be accessible by road, must have a control village immediately upwind, must permit accurate flying at low altitude and must contain the types of vegetation required, seriously limited the number of suitable sites. Great help was given the Porton team both in selection and preparation of the trials areas by Lt. Col. A. C. Stevenson, R.A.M.C. and his team of Sergeant entomologists, who commenced their survey work in May.

11. Prior to the trials over square mile areas, a preliminary trial using two aircraft only, was carried out over an area 800 yards square, referred to as the "26th Mile-stone Area". This was a purely exploratory trial to test and develop sampling and flying technique under W. African conditions. The individual results obtained in the square mile area trials are given in Table A. In addition a number of small air sprays were carried out over a formalised layout to obtain performance data (see Appendix E) and over various types of vegetation to obtain figures relating to spray penetration (see Appendix H).

MATERIALS

12. Both DDT/Oil solutions and oil-in-water emulsions containing DDT were used and compared as air sprays. Details of their specifications, physical properties and method of their preparation are given in Appendix D. Briefly, however, two oil mixtures containing 0.6% and 2.9% pure DDT by weight, and two dilute aqueous emulsions containing 0.5% and 1% pure DDT by weight, were used in different trials. The basic constituent of all the spray mixtures was a 7% (approx.) solution of pure DDT in lubricating oil of low volatility. Oleic acid was added to the DDT/Oil mixtures to increase their spreading power; the emulsions also contained a spread-aider. For purposes of physical assessment the oil mixtures were dyed but the emulsions could not be characterised because the dye available caused breakdown of the system.

13. In the first trial, 500 imperial gallons of an emulsion spray mixture containing 50 lb. of pure DDT were put down on a square mile. In spite of the satisfactory results obtained against adult mosquitos in this trial, the quantity of spray mixture was doubled in later trials as it was felt that with the lesser

Throughout this report, the expenditures of spray mixtures are given in Imperial gallons per square mile. Expenditures of DDT are given, either in pounds per square mile or in milligrams per square metre. For the benefit of those used to other units of measurement, the following table is given.

TABLE A (approximate equivalents)

Mixture	lbs. of pure DDT per sq. mile	ozs. of pure DDT per acre	grams. of pure DDT per acre	Mg. of pure DDT per sq. metre	Imperial quarts per acre	U.S. quarts per acre
DDT Emulsion No.1 At 1000 Imperial gallons per sq. mile (Nominal pure DDT content: 0.5% by weight (Actual pure DDT content: (47.5 lb./1000 Imp. gal.	47.5	1.2	34	8.3	6.3	7.5
DDT Emulsion No.2 At 500 Imp. gal. per sq. mile (Nominal pure DDT content: 1.0% by weight (Actual pure DDT content: 47.5 lb./500 Imp. gal.	47.5	1.2	34	8.3	3.1	3.7
DDT/Oil Mixture No.1 At 1000 Imp. gal./sq. mile (Nominal pure DDT content: 0.6% by weight (Actual pure DDT content: 52 lb./1000 Imp. gal. Sp. gr. 0.86	52	1.3	37	9.1	6.3	7.5
DDT/Oil Mixture No.2 At 1000 Imp. gal./sq. mile (Nominal pure DDT content: 2.9% by weight (Actual pure DDT content: 253 lb. per 1000 Imp. gal. Sp. gr. 0.88	253	6.3	179	44.3	6.3	7.5

The above equivalents are all based on the actual DDT content of the mixtures used - vide: Appendix D.

amount any errors in flying or any S.C.I. failures might cause serious gaps in the ground contamination. By using 40 tanks per square mile, and laying 20 parallel swathes across the area, such errors would be compensated by spray released further upwind.

14. An expenditure of 50 lb. pure DDT per sq. mile was used in most of the trials, but in two trials this expenditure was increased fivefold to discover if more satisfactory results could be achieved against larvae and adults by using a heavier dosage of DDT.

15. The desirability of having a spreading agent in an air spray mixture was demonstrated by an extensive survey of the film pressures obtaining on natural water surfaces in the trial area. It was found that these natural water surfaces fell into two main groups:-

(i) those with film pressures less than 30 dynes/cm.

(ii) those with film pressures greatly in excess of 45 dynes/cm.

It would be extremely difficult to ensure that spray drops will spread on group (ii) but by raising their spreading pressure to at least 25 dynes/cm. the drops can be made to spread on the majority of group (i) surfaces. The spreading pressure of the DDT/Oil mixtures used in the present trials was increased to about 28 dynes/cm. by the addition of 0.5% oleic acid; the spreading pressure of the emulsion spray mixtures was 46 dynes/cm. These matters are discussed in more detail in Appendix I.

16. Because of its general availability in most operational areas, the spray tank selected for use was the American tank, Airplane, M.10, containing 25 imperial gallons of charging. Certain modifications to the tank were carried out:-

(a) Adaptors and adaptor fairings were required for use on British bomb carriers.

(b) Bakelite emission discs were chosen as being more reliable than the American glass disc.

(c) The emission outlet was restricted to 2½ in. diameter by fitting thimbles as used in laying smoke screens.

It was found unnecessary to fit inlet discs for the trials and no significant spillage resulted from this omission.

17. In spite of their light construction and outdoor storage under tropical conditions with the consequent fluctuations in temperature, the tanks proved most reliable in use and only 1 out of 42 developed any leaks. In all the trials, small ones included, only 4 S.C.I. failures occurred and of these 3 were due to faulty electrical circuits on the aircraft.

Sampling Procedure

A. Physical

18. Preliminary trials showed the impossibility of using anything like normal air spray sampling layouts. With the very limited number of reliable personnel the sheer physical effort entailed in setting out sampling apparatus in areas where it was frequently necessary to hack a path was prohibitive. Moreover the showers which so frequently occurred during trials and thus necessitated the replacement of sampling envelopes were a powerful factor in making extensive layouts undesirable. For this reason sampling was restricted to selected points where information regarding the penetration of spray might be obtained or to entomological sampling sites where an assessment of contamination density would be of value.

19. In the trials using oil solutions of DDT, the mixture was dyed and sampling was by envelopes. Using the emulsions which were not dyed (see para. 12), glass plates were set out to demonstrate the presence or absence of spray at any given point. There is little doubt that the methods of assessment available in W. Africa were not altogether satisfactory under tropical conditions, and some more suitable technique should be developed (see Appendix J).

B. Entomological

20. The methods of entomological sampling used are detailed by Prof. Buxton in Appendix B, but briefly they were as follows:-

Certain inhabited bedrooms were selected both in the village or villages to be sprayed and in the control village and villages outside the area. These rooms were visited by a sergeant entomologist (usually twice a week) and were sprayed with pyrethrum/kerosene from a flit gun. Prior to this "flitting" the floor was covered with a sheet, and all disabled mosquitos falling thereon were counted. The total number killed divided by the number of rooms treated (generally six) gave a room index for the village. 24 hours after a DDT air spray had been discharged over the area, the room index was again determined and at such later dates thereafter as were considered necessary. In this way, any effect of the DDT air spray upon the adult mosquito population in the area would be shown by variation of the room index of the sprayed village provided, of course, that the indices in control villages underwent no violent natural fluctuations during the period of assessment.

21. In some trials sheets were put down in the catching stations and examined after the flight to see whether spray penetrated these very open and flimsy houses in quantity sufficient to kill adults resting therein during the day-time and in addition brass wire cages containing artificially bred culicines were set out in the rooms.

22. Besides "adult" sampling the effect on larvae was checked by taking dips from the selected breeding places before and after spraying. In some cases artificial breeding places were improvised to augment the natural population or to try the effect of the air spray under some specialised local condition.

Weather

23. In the areas around Takoradi where the trials took place, the temperature was generally fairly constant with a daily maximum of between 85 and 90°F and a humidity of about 80%. Rainfall varied between 50 inches per annum at Takoradi to 100 inches at Axim 40 miles to the West; these two towns roughly delimit the trials area. The prevailing winds were S.W. with a surface velocity of 5-15 mi/hr. For nearly all the trials cloudy conditions prevailed with about 7/10 at 1000-2000 feet. A detailed description of local climatic conditions is attached at Appendix F.

Flying Procedure

24. The Vengeance aircraft provided for the trials were a most unsuitable type for low spray, the Mark II's in particular having very poor forward visibility. Under these conditions the aircrews are to be congratulated on the very high standard of flying which they set themselves and maintained. These inherent disadvantages of the Vengeance had two major effects:-

(a) It was impossible to adhere to a standard height/wind product owing to the fact that the aircrews could not fly low over wooded and hilly country, and thus not only was a variable introduced from trial to trial, but in some cases the spraying height was not as low as was desirable.

(b) The Vengeance flies "nose high" at speeds below about 220 m.p.h., thus still further restricting forward visibility under this speed. For this reason no determination of the optimum spraying speed was possible.

25. After trying other formations, the best method of spraying was found to be by a flight of five aircraft in V formation with a lateral spacing of about 100 yards between aircraft (see photograph 12). Quite apart from the fact that this spacing gave a theoretically satisfactory ground pattern for an expenditure of 40 tanks per square mile, it also enabled the aircraft to keep accurate formation on the flight leader and thus reduced the number of smoke signals required.

26. A number of the areas originally selected for trials were delimited by "rides" cut through the forest or scrub. In practice it was found that these rides alone were not a sufficient guide for aircraft requiring to put down spray with the accuracy needed for experimental work, and that while they were of use for getting about the area on foot, this did not justify the enormous labour of cutting them through the jungle.

After trying more elaborate systems, it was found that, provided the flight leader was given two smoke candles in line to indicate his spraying track and that the point of firing the first S.C.I. was given, either by a natural landmark or by further smoke signals, very accurate spraying was possible. At the speed enforced by forward visibility (viz. 220-230 m.p.h.), the second S.C.I. was fired 9 seconds after the first, this resulted in a swathe from the two tanks about 2000 yards long.

27. Ground to Air control was from a Humber car fitted with a Bendix radio. On the two occasions when the wireless broke down a system of signals by Very pistol was employed with complete success.

28. The refuelling and re-arming technique used at the base, the times between sorties and the man-power effort required, are of practical interest and are discussed in Appendix G.

DISCUSSION OF RESULTS

29. The entomological results obtained are detailed in Prof. Buxton's memoranda attached as Appendices B and C, and are given briefly in Table B. Generally speaking however the following facts were established:-

30. Under West African conditions the physical assessment of air sprays offered great difficulty and for this reason too much reliance should not be placed on any very small dosages recorded in the trials and quoted here or in the relevant appendices.

31. It very soon became apparent that the filtration of air spray by the vegetational canopy was more drastic than had been anticipated. In addition to assessing this effect in the main trials it was decided to carry out a number of small scale trials to determine the approximate degree of filtration. A separate Memorandum, attached hereto as Appendix H has been issued on this subject because it is of general application and is important not only in connection with DDT air-sprays. An approximate assessment of the filtration effect is given in the Appendix, the penetration being expressed as a percentage of the density of contamination by volume which could be expected on the ground were all vegetation cleared away, but as a rough indication of the penetration it can be stated that less than 1% reaches the ground below primary evergreen rain forest and about 20% reaches the water surfaces in mangrove or freshwater forest swamps.

(a) Effects against Mosquito Larvae

32. This drastic filtration of the spray by vegetation of different kinds was undoubtedly the cause of the very variable and inconsistent results obtained against mosquito larvae breeding under cover. In some cases kills and failures to kill were observed at points separated by only a few yards. Complete kills were always obtained at breeding places open to the sky and from three trials it appears probable that a 100% kill of larvae occurred whenever spray containing 0.8 mg/m^2 (about 1/100 lb. per acre) of pure DDT reached the water surface, and that where less than 0.2 mg/m^2 reached the surface no kill took place. It must be emphasized that the use of these small doses is not recommended in practice.

In some cases larvae were killed in very densely covered breeding places through the spray being carried down on a flowing stream. In this connection however it must be borne in mind that the bulk of the larvae were species of anophelines which breed in sheltered places and far better results might be anticipated against the larvae of A.gambiae and other species breeding in open water.

(b) Effects against adult mosquito populations (see Table B)

33. It seems that the catching station technique, supplemented to a slight extent by the use of bred mosquitos in wire gauze cages, was the only feasible method of estimating the effect of spray on adult mosquitos; it is to be remembered that day-biting mosquitos were completely absent.

If the catching station technique is used for some weeks before a flight, and if a considerable reduction in mosquitos is observed afterwards, it may be due to one of several causes (assuming that no such fall occurs in the control villages, and that one has reason for thinking that the reduction is too great to be due to "chance"). The possible causes of reduction of mosquitos in catching stations are:-

(i) The indirect effect of destruction of larvae in the water.

(ii) Entrance of spray into a house, in quantity sufficient to kill mosquitos at rest there.

(iii) Contamination of surfaces (ground, leaves, thatch) so that mosquitos moving about in the following night are killed.

Of these we obtained no evidence (i) whether the lavicidal effects reduced the house counts; it would be important only if the effect was great and lasting. Much attention was given to the possibility of spray entering houses (ii). No evidence was obtained that it did so, either from adult Aedes in wire gauze cages, or from the Anopheles adults which were known to be in the houses, and which did not fall dead on sheets on the ground. The houses were peculiarly open, (photos. 13 and 14) and one felt that spray would have entered them, if it can enter houses of any type.

As to the possibility (iii) of adults being killed during the night after the trial by contacting contaminated surfaces, most interesting results were obtained:-

1. At Natiem, using 250 lb. of pure DDT/sq. mile in 1000 gallons of oil spray mixture, a reduction of over 85% of A.funestus followed within 24 hours of spraying. A similar reduction took place in two smaller villages in the sprayed area and none in two controls. The effect lasted nearly a fortnight. The conclusions are confirmed by statistical analysis (Appendix C).

2. This was confirmed at Ntangufo, with very similar results and the same dose of DDT and solution.

3. At Ataraso (first experiment) a similar reduction of adults, lasting for a shorter period, was obtained with 500 gallons of emulsion containing 50 lb. pure DDT/sq. mile. But in other experiments where 1000 gallons of spray mixture containing 50 lb. of DDT was deposited on square mile areas evidence was inconclusive and it was impossible to say whether or no the spray had any effect on the adult mosquito population.

(c) Other effects

34. In no trial was any damage reported to domestic birds and animals, fish or vegetation. No noticeable decreases occurred among other insect life.

35. In one trial spray fell onto a densely sedge covered swamp, and a short while later a shower of rain fell but this did not succeed in washing the spray down onto the water surface in sufficient quantity to kill larvae.

36. It is known that in all trials the bulk of the spray released fell on growing vegetation of various kinds. In spite of this and in spite of the known chemical stability of DDT, the effects of the spray against larvae and adults were transient and wore off after varying periods of time up to twelve days. It would appear probable therefore that certain types of growing vegetation, including water plants, can render fallen DDT spray innocuous to both larval and adult mosquitos. This important effect is now under investigation.

37. A study of the air movements in West African Jungle showed that they were very light and quite unpredictable in direction. This being the case, in planning the spraying tracks, only the wind conditions above the canopy can be considered.

Expenditures

38. The impossibility of further work owing to exhaustion of materials and the onset of the dry season leave many questions unanswered. It would for example have been interesting to discover at what exact expenditure of DDT between 50 and 250 lbs. per square mile using 1000 gallons of spray mixture the very substantial residual effect obtained with the latter expenditure commences to be apparent. It would be of great operational value too if it had been possible to confirm the results achieved in the Ataroso trial where an 80% reduction in mosquito population was recorded with an expenditure of 500 imperial gallons containing 50 lbs. DDT (i.e. ten Vengeance Aircraft) per square mile.

39. Under these circumstances it is difficult to lay down any hard and fast rules, but, as a guide for operational use of DDT air spray, it may be stressed that the effects of DDT air spray are a function both of the expenditure of DDT and the drop density established in the area.

In fact three different expenditures were used in the trials over square mile areas:-

(a) 500 Imperial gallons of emulsion containing 1% by weight of pure DDT (50 lbs.).

(b) 1000 Imperial gallons of emulsion or oil solution containing 0.5% of pure DDT (50 lbs.).

(c) 1000 Imperial gallons of oil solution containing 2.9% of pure DDT (250 lbs.).

The results achieved by these different expenditures are summarized below:-

(i) Effects against larvae

40. All these expenditures gave a 100% kill of larvae breeding in open water. None of them could be guaranteed to kill A.funestus larvae breeding under vegetational cover.

(ii) Effects against adults

41. Only one trial was done using 500 gallons of spray mixture containing 1.0% DDT per square mile. In this trial there was an 80% disappearance of the adult mosquito population within 24 hours. Fluctuations in the mosquito counts in the control villages made it impossible to determine for how long this effect was maintained.

42. Four trials were done using 1000 Imperial gallons of spray mixture (1 oil solution, 3 oil in water emulsions) containing about 0.5% pure DDT per square mile. In None of these trials was there any marked decrease in the adult mosquito population.

43. In two trials, 1000 Imperial gallons of oil solution containing 2.9% pure DDT (this is roughly equivalent to the standard American solution containing 5.0% commercial DDT) was sprayed over the square mile. The evidence in these two trials is of particular value, because in both cases there was more than one sprayed and control village. In both cases an immediate decrease (80-90%) of the adult mosquito population occurred and this decrease was maintained for 12-14 days.

Discussion of Expenditures

44. The position as regards a spray mixture of 250 lb. pure DDT in 1000 Imperial gallons per square mile appears to be quite clear. It is different in the case of the two expenditures, a and b (para. 39). It is dangerous to dogmatise on the result of a single experiment, but it may be very significant that a 1% DDT content caused a substantial reduction in the adult mosquito population whereas a 0.5% DDT content did not. The 0.5% DDT content was contained in 1000 gallons of spray liquid, and, theoretically therefore, the adult mosquito had twice as many chances of contacting the DDT as in the case of a 1% content in 500 gallons; yet the 0.5% content failed to achieve worthwhile results in each of four trials, whereas the solitary use of 500 gallons of 1% DDT content caused an 80% reduction in the adult mosquito population. These results may have a connection with the possible sorption of DDT solutions and emulsions by growing vegetation (see para. 36).

CONCLUSIONS

45. 20 x Vengeance Aircraft each carrying two M.10 Spray tanks fitted with 2½ in. emission thimbles and firing the tanks in sequence can put down an effective DDT spray over one square mile of typical West African countryside.

46. An immediate and substantial reduction in adult mosquito population occurs if 1000 imperial gallons of spray containing 250 lbs. of pure DDT (2.9% by weight) is put down on one square mile and this reduction is maintained and may even be increased over a period of 12-14 days.

47. Using this expenditure a satisfactory kill of mosquito larvae breeding in sheltered places cannot be guaranteed, but all larvae breeding in open standing waters are killed. This effect can equally well be achieved by using 50 lbs. DDT in the same quantity of spray liquid, and was also achieved in the only trial using 50 lbs. DDT in 500 gallons of pure emulsion.

48. There appears to be no difference in the effectiveness of the larvicidal action of oil solutions or oil in water emulsions, containing the same concentration of DDT.

49. The effects of the small variable air movements under the jungle canopy cannot be predicted and need not be considered in calculating the spray effect required.

50. The formation which requires the least guidance in the way of smoke or other target indicators is a 'V' formation of five aircraft with a lateral spacing of 100 yards between aircraft.

51. The M.10 tank is sufficiently robust to withstand use with non-toxic chargings under tropical conditions and no inlet discs need be fitted.

52. Both the DDT oil solutions and oil in water emulsions used stored well under tropical conditions over a period of 3 months.

RECOMMENDATIONS

53. Further work both in the field and the laboratory, is required to establish:-

(i) The minimum area dosage of DDT to obtain a worthwhile decrease in the adult mosquito population which will be maintained for, say, at least 7 days, under varying conditions of terrain and climate.

(ii) The least expenditure of spray liquid which will achieve the same results.

(iii) Whether the anti-adult efficiency of DDT air spray deposited on vegetation would be altered by permitting partial or complete crystallization of the DDT from the fallen drops. (Note:- In the present trials it was arranged that no crystallisation could occur.)

(iv) The possibility of sorption of DDT sprays by certain types of vegetation.

(v) At what height above the ground adult mosquitos are most likely to contact the vegetation during their migration to the villages.

(vi) The possibility of decreasing the mosquito population of a village merely by laying a swathe of DDT spray between the village and the breeding places.

(vii) Whether a spray with oil alone will repel the mosquitos and thus cause a decrease of population within the sprayed area.

(viii) A satisfactory system of target indicators under operational conditions. Smoke shell, mortar bombs or a pathfinder technique are all possible.

(ix) The minimum necessary spreading pressures for drops of DDT air spray on natural water surfaces in many different localities.

(x) More satisfactory methods of sampling air sprays under tropical conditions.

ACKNOWLEDGEMENTS

54. The thanks of Prof. Buxton and the Porton team are owed to A.H.Q.W.A., G/Capts. Hanmer and Rankin and the personnel of R.A.F. Station, Takoradi for their whole-hearted assistance in the trials and to Mr. Burner, Provincial Commissioner for his co-operation. Also to Lt. Col. A. C. Stevenson, R.A.M.C. and his sergeant entomologists, to F/Lt. Hedley and the personnel of 110 (H) Squadron for their keenness and their very high standard of flying under most difficult conditions and for the excellent work of the ground crews.

55. We are also indebted to F/Lt. Spurr, Senior Met. Officer, R.A.F. Station, Takoradi for his practical assistance in carrying out the trials and for supplying Appendix F.

(Sgd.) R. M. A. Welchman.

Brigadier,
Chief Superintendent,
C.D. Experimental Station.

PORTON.
WDP/EMP.

TABLE B

Tabulated results of Individual trials over square mile areas

All areas were sprayed by separate sorties of five aircraft each.

In all cases the kill of larvae was rendered very erratic by the presence of protective vegetation.

No. of Trial	Site & Date carried out	Type of Terrain	Mixture used	EXPENDITURES: No. of A/C	EXPENDITURES: Galls. of charging per sq.ml.	EXPENDITURES: lbs. of pure DDT per acre	WEATHER: Air temp.	WEATHER: Relative Humidity	WEATHER: Mean wind spraying height	ROOM INDICES: Sprayed Villages: Before	ROOM INDICES: Sprayed Villages: After	ROOM INDICES: Control Villages: Before	ROOM INDICES: Control Villages: After	Residual effect	Remarks
2	ATAROSO 20.9.44.	Mainly evergreen rain forest, much of it primary. Some dense secondary growth and a treeless sedge covered swamp.	An oil in water emulsion, containing 1% by weight of pure DDT.	10	500	0.08 (9 mgm/m²).	82°F.	88%	7 ml/hr.	22.0 39.0x 17.0x	4.0 13.0 11.0	9.0	15.0	The reduction seemed to continue, but this is uncertain as counts in the control village were also falling.	The mosquito population was mainly A. funestus. No S.C.I. failures. x = Villages on edge of the area.
3	BUSUA 27.9.44.	Much dense secondary forest. About half the area under cultivation. Two mangrove swamps.	A lubricating oil/gas oil mixture containing 0.6% pure DDT.	20	1000	0.08	84°F.	85%	14	2.5	1.7	14.5	10.0	Indeterminable.	Mosquitos were mainly A. melas, breeding in the Avicennia swamp. Some Aedes aegypti. 3 S.C.I. failed.
4	NATLAN 11.10.44.	Mainly low, but dense secondary scrub, interspersed with maize and cassava. One area of freshwater swamp forest.	A lubricating oil/gas oil mixture containing 2.9% pure DDT.	20	1000	0.39 (44 mgm/m²)	82°F.	90%	7	12.0 7.0 2.5	1.5 1.0 2.0	6.0 5.0 5.0 7.0	6.0 7.0 4.0 6.0	The mm quito population did not increase again until 12 days had elapsed.	Mosquitos mainly A. funestus. No S.C.I. failures.
5	ATAROSO No.2 18.10.44.	As for 2.	As for 3.	20	1000	0.08	84°F.	80%	4-7	11.0+ 13.0x	4.0+ 22.0x	20.0	16.0	Indeterminable. All effects on adult mosquitos recorded in this trial are open to doubt owing to movements of population in the villages.	+ = Average for two rooms only. x = Village on edge of area. 1 S.C.I. failure.
7	AWUSIAJA 26.10.44.	Mainly under cultivation, containing some recent secondary growth.	An oil in water emulsion containing 0.5% pure DDT.	20	1000	0.08	86°F.	77%	8	15.0	11.0	10.0	20.0	Indeterminable.	Mosquitos mainly A. funestus. No S.C.I. failures.
8	ASANI 1.11.44.	Similar to 7.	As for 7.	20	1000	0.08	82°F.	75%	0-4 very variable.	32.0	18.0	18.0 14.0	44.0 18.0	Indeterminable.	Mosquitos mainly A. funestus. No S.C.I. failures.
9	NTANGUPO 3.11.44.	Mainly cultivated areas or areas of recent secondary growth.	As for 4.	20	1000	0.39	86°F.	73%	6-14	25.2 43.3	6.3 5.1	8.8 24.0	8.2 33.0	The reduction continued until, by the fourth day, the room indices in the sprayed villages were below 1. They began to rise again 7 days later.	Mosquitos mainly A. funestus. No S.C.I. failures.

D.2088. P/S-4.44.

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1

LOWLAND EVERGREEN RAIN FOREST

2

"AN IMPENETRABLE MASS OF CLIMBING HERBS"

3

SECONDARY GROWTH 15'-30' HIGH

4

AN AVICENNIA MANGROVE SWAMP

5

FRESHWATER SWAMP FOREST

6

A DENSE BAMBOO CLUMP OVERSHADOWING A STREAM

7

A TYPICAL CULTIVATED AREA
MAIZE AND OIL PALMS

8

CASSAVA, SHOWING THE COMPARATIVELY
LIGHT VERTICAL OVERHEAD COVER

THE SAME CROP, SHOWING THE MANY LAYERS AVAILABLE
FOR FILTERING OUT A SPRAY DRIFTING HORIZONTALLY

10

A TYPICAL SHELTERED BREEDING PLACE OF A. FUNESTUS

11

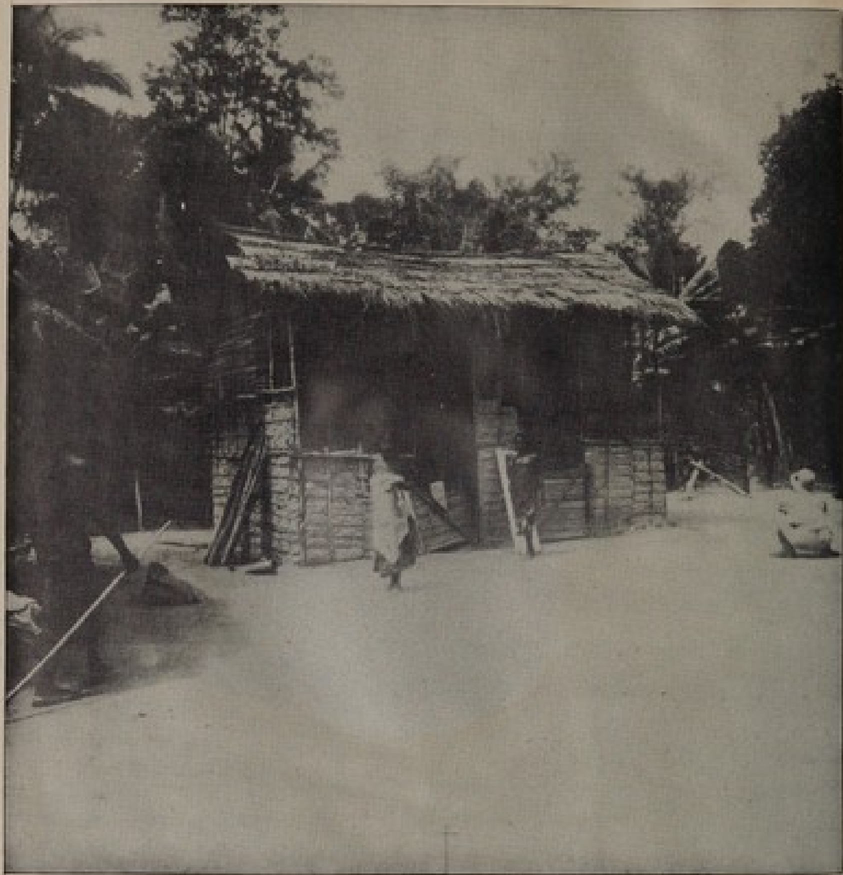
SETTING OUT A SAMPLING ENVELOPE AT AN
ENTOMOLOGICAL SAMPLING POINT

N.B. This also shows the sheltered type of breeding place selected by A. Funestus. (see para. 9)

12

"THE AIRCRAFT FLEW IN V FORMATION"

13



LIGHTLY CONSTRUCTED NATIVE HOUSES
SHOWING THE OPEN GABLE ENDS

14

TYPES OF VEGETATION IN AREA OF SPRAY TRIALS

by Prof. P. A. Buxton, F.R.s.

I have attempted to make a description of the vegetation of our area, so as to convey some impression of it to those who have not seen it, avoiding the use of technical botany. The Chief Conservator of Forests of the Gold Coast, and members of his staff have commented on the draft of the note and greatly increased its value. I have adopted their suggestion and use the names for different types of forest defined by Burtt Davy in "THE CLASSIFICATION OF TROPICAL WOODY VEGETATION-TYPES", (University of Oxford, 1938). The use of this system should be general, for it will help readers in different areas to understand one another.

The area under consideration lies within five degrees of the equator and receives abundant rainfall. The surface rock is red "laterite", most of it of the consistency of clay. The lateriate lies in irregular indulations, so that except for a coastal strip less than a mile wide, there is no flat ground. But the hills are all small and nowhere exceed 300 feet above sea level; none of the slopes are very steep and there are no cliffs.

The whole area except a narrow coastal strip, was formerly covered by Lowland Evergreen Rain forest, but owing to the system of shifting cultivation very little primary forest remains, for almost every part of our area has at one time or another been felled for purposes of cultivation, i.e. the forest is mostly secondary. There was, however, some primary forest along the river in our area at Ataraso.

The density of this secondary forest depends on the period which has elapsed since the ground was last cleared, and several types may be distinguished:-

A. Where a long period has elapsed one has a type of forest which to anyone except a forester, would appear to be primary Lowland Evergreen Rain-forest, similar to that seen elsewhere in the wet tropics. It is composed of a very large number of species of trees, nearly all of them evergreen. The tallest trees are silk cottons (Ceiba) of which we measured individuals of 170 feet.

The general level of the canopy is perhaps 20 to 40 feet lower. As the canopy often consists of three or even four layers, it is certainly very thick and difficult to penetrate from above. Nevertheless, shafts of sunlight do come down to ground level here and there. The area of sky visible from the ground in this type of forest was seldom as much as one tenth, generally very much less. In this type of forest one can walk in most directions picking one's way, though one can never walk in a straight line. Herbs and low bushes were rare and grasses absent, probably because the canopy shuts off so much light. In comparison with true rain-forest such as occurs in Panama, Ceylon, the New Hebrides, Samoa, and many other places, the writer was struck by the scarcity of creepers and bush vines. Ferns, orchids, mosses and other epiphytes growing on the branches of the trees are quite rare. Large figs (Ficus) with the banyan habit are uncommon.

We find that in studies on cocoa plantations the local Department of Agriculture took readings of light under various types of shade, placing a white card in different places and measuring the reflected light with a photo-electric cell. Taking open noon sky as 100, the following readings were recorded.

1. Cocoa growing under high evergreen trees, above the cocoa 8.0, below the cocoa on the ground 0.7.

2. Cocoa growing without shade, below the cocoa on the ground 3.5 to 1.9.

The reader is to understand that a cocoa bush has large evergreen leaves, and is roughly as large and as dense as a large laurel bush. These figures indicate how little light reaches the forest floor, and perhaps help the reader to grasp what a dense evergreen canopy can exclude.

As the West African forest flora is not entirely unlike that of South East Asia, it is perhaps worth while to include more precise botanical information. In addition to the great silk-cottons (Ceiba) one might mention the following genera as important members of the highest level of the canopy. Chlorophora, Cynometra, Entandrophragma, Khaya, Lophira, Mimusops, Piptadenia, Sarcocephalus, and Terminalia. Among the smaller trees, there were species of Cola, Diospyros, Garcinia, Scottelia and Strambosia.

The variety of trees is very great, an important point of distinction from temperate forests. Enumerations have been carried out by foresters and it is known that from 50 to 200 distinct sorts of trees (excluding shrubs and bushes) can be found in a square mile.

Even when the forest has regenerated into something approaching its original state, it is often broken up by villages and the surrounding area of cultivation.

B. The second type of vegetation was that growing in areas which had rather recently reverted from cultivation. In these areas one found a relatively small number of species of tree or bush, often only 15 to 30 feet high, forming an extremely dense cover and impenetrable at ground level unless one cuts one's way. A very characteristic tree in these areas is the oil palm (Elaeis). Species of Albizzia are common, and the gregarious Musanga covers large patches.

C. Considerable areas of the forest are under several feet of water even in dry spells; they are presumably the Freshwater Swamp Forest of Burtt Davy. A characteristic of the flora of these areas is the spiny climbing palms (Calamus and others) resembling the rattans of Malaya; common trees are Mitragyne and Uapaca. Large clumps of enormous bamboos (up to 80 feet) were common beside streams in areas liable to flood. They completely dominate certain spots and no undergrowth occurs beneath them.

D. In addition to these areas of Freshwater Swamp Forest, there are also open swamps without any trees. The dominant plants are sedges (Cyperaceae), aroids (Araceae) and Scitamineae. In some of these open swamps, large ferns predominate. On the open water one finds Waterlilies and Pistia.

E. There were also large numbers of coastal swamps caused by sand bars in the mouth of rivers. Some of these were brackish and contained mangroves, forming a tropical Mangrove Woodland. It will be remembered that in certain parts of West Africa Anopheles melas (formerly regarded as a variety of A.gambiae) breeds almost entirely in one particular type of mangrove (Avicennia) which occurs in 'Orchards' on the landward side of the main area of mangrove. The study of mangrove areas and their spraying from the air was part of our programme; unfortunately, in spite of very careful search, only one suitable area, Busua, could be found. Avicennia occurred in many places, but generally grew on rather a steep slope and held almost no breeding places and very few Anopheles larvae. The area at Busua produced a fair number of Anopheles melas and they were increased by a little spade work.

F. Cultivation. There were considerable patches of Cassava and maize round the villages. The cassava provided very light cover four to six feet high, but was so open that one could pick one's way through it in all directions. Looking up from under cassava one found that about 5/10ths of the sky was covered. The maize had been harvested and was dead and broken down. Some of the swamps had been cleared of forest and sown with rice, (which in this part of the world is broadcast in a very primitive way, without irrigation or terracing).

When land has been under maize and cassava for a few years the villagers cease to weed it, and it becomes covered with a herbaceous yellow-flowered Sunflower. This forms a dense mass some ten feet high, twined together with climbing herbs and impenetrable without a knife. It is gradually replaced by bushes and then small trees and passes through stage B (above) finally reverting to forest (Stage A), unless it is cut down and again brought under cultivation in the interval.

APPENDIX B TO PORTON REPORT NO. 2669

PREVALENT ANOPHELES, AND ENTOMOLOGICAL PROCEDURE

by Prof. P. A. Buxton, F.R.S.

1. INTRODUCTION

Terms of reference indicated the sort of country in which the tests were to be carried out. Flights were to be made over vegetation of a number of types including dense evergreen forest, and also areas of mangrove. In order to test the larvicidal effect of the spray it was desirable to find breeding places of mosquitoes under these types of vegetation. But it was also necessary to have farms or villages to serve as catching stations, so that the effect of the spraying on wild adult mosquitos might be observed. In addition the area had to be accessible by road even after heavy rain, so that the wireless and other heavy equipment could be brought to the spot.

It was no easy matter to satisfy all these conditions, for in West Africa, and indeed in the tropics in general, people settle where the soil is good, they clear the forest, plant crops, and often produce conditions favourable to the breeding of mosquitoes. Some of the cultivated area near such a village may well have gone back into dense low secondary jungle, but villages are never inside unaltered evergreen Rain Forest. It was, however, possible to select areas of about a square mile, accessible by road, and also containing a village or two about the middle, with patches of cultivation and secondary low jungle, and also patches of high evergreen forest; close to most of these areas there were other villages up wind of the square mile; these were also used as catching stations and afforded controls to the village in the centre. In the choice of areas we received a great deal of assistance from Lieut. Col. A. C. Stevenson, R.A.M.C., who had already given much time and energy to searching the countryside before our arrival.

The note entitled "Types of Vegetation in area of spray trials" should be consulted. (Appendix A.)

2. ANOPHELINE MOSQUITOS

The mosquito fauna of the area in which we worked was unexpectedly limited, for only five species of Anopheles occurred with any frequency, and none of them were really abundant during our visit.

Anopheles gambiae generally bred in road side ditches, shallow depressions in cultivated land and other temporary puddles which occurred after rainy spells. It seemed to breed most frequently in and around villages.

Anopheles melas (we accept the view that this is a species distinct from Gambiae though clearly very nearly related) breeds only on the landward side of mangrove swamps, among the respiratory roots of the particular mangrove known as Avicennia. In our area this mosquito was fairly common at Busua; here the conditions seem to be similar to those studied by Muirhead Thomson near Freetown, the Avicennia zone containing small fresh seepages, and being above the reach of all tides except spring tides. Elsewhere in our area, Avicennia was common at many points, but we failed to find A. melas breeding. The identification of this mosquito at Busua was confirmed by the examination of eggs. It is known that Avicennia occurs widely in S.E. Asia, where Anopheles sundaicus, confined to this particular sort of mangrove, is not known to us.

Anopheles funestus bred in more permanent swampy places particularly if they were grassy. In several of our areas it bred in swamps which had been cleared of trees and sown with rice, but its larvae were also common in grassy roadside ditches which held water permanently.

Anopheles obscurus (including var. nowlini) bred in shallow stagnant pools of brown water under heavy forest, and particularly under clumps of giant bamboo. It was widely distributed but rarely common.

Anopheles cinctus bred in very small numbers at the edge of the attractive mountain streams which ran through the forest in many parts of the area.

From the point of view of aerial spray it is to be understood that the larvae of A.gambiae are often fully exposed to sky and sun. A.funestus are among grass or sedge, but not under dense trees.

A.melas is found under the very light shade of the Avicennia mangrove. A.obscurus and cinctus occur in forest, under dense shade, the first in stagnant the second in running water. Unfortunately neither was common, indeed where they did occur one might get one or two larvae in ten dips with a ladle, but they were absent from many waters which looked suitable.

The adults of A.gambiae and funestus (and of melas in suitable places) feed mainly on human blood, at night, and rest in the house afterwards. They may therefore be studied by "catching stations", i.e. particular rooms in which people sleep, and from which mosquitos are carefully collected at regular intervals. But adults of A.obscurus and cinctus do not appear to bite man, and were never caught in houses; we do not know where they rest; on these two species therefore one could only assess the effect of the spray upon the larvae, and that with difficulty.

3. CATCHING STATIONS

In most villages the type of house used as a catching station had a mud floor, solid mud walls, and a roof of galvanised iron or thatch. In some villages, e.g. Ataraso and Natiem, there was a space between the top of the wall and the roof and there was also a triangular opening in the gable. It was through these spaces that mosquitos entered, for the doors and windows (which were framed and close fitting) was always kept shut at night. As the mosquitos entered the room through the top one could not erect a ceiling of calico (which would certainly have made the actual catching easier). This type of house is so open that you can read inside it, when doors are shut.

Busua is more wealthy and sophisticated. The roof comes right down on the top of the wall, and the gable space is built up; moreover the rooms are ceiled with poles and clay. Hardly a chink could be seen when the door is shut.

The house is generally divided inside by a screen of reeds into a cooking room and a sleeping room; in the latter there is a rough bedstead. It was the sleeping room that was always used as a catching station, and it was not used unless people had actually slept in it the previous night. We generally selected six sleeping rooms in each village and collected mosquitos twice a week. The same rooms were always studied, unless the owner went away. A few villages contained less than six sleeping rooms.

Mosquitos were collected by putting sheets on the ground and using a flit gun with army spray (i.e. pyrethrum in kerosene). An attempt was made to do this early in the morning, but this was not always possible owing to distance of villages from headquarters, and the fact that sometimes a house was locked.

The work of collecting mosquitos was done by trained African staff, a Sergeant entomologist (British) being present on the majority of occasions; there was no evidence that the catch was less when the Sergeant was not present, and the opinion was formed that these Africans were reliable. The Sergeant invariably identified the catch and kept the books.

4. RAINFALL AND MOSQUITOS

For meteorological data see Appendix F. The area we worked in had a mean annual rainfall of sixty to eighty inches, with a peak in May or June, and a smaller peak in October. Completely rainless months are unusual. The table in Appendix F gives actual rainfalls for the months before and during our experiments.

The lack of rain in August and September had an unfortunate effect on our work, for it almost abolished the breeding of Anopheles gambiae, and reduced the A.funestus. Had we been able to start experiments in August as originally planned we should have had abundant adults and larvae of both species. Owing to delay in the aircraft and stores, the first experiment (a very small one) took place on 4th September. After that we were compelled to work on those places which had a population of A.funestus, several villages in gambiae areas having to be abandoned in spite of much preliminary work given to them.

The fall in adult A.gambiae in catching stations and the relative stability of number of A.funestus are well shown in Table 1. The village of Tomento had a mosquito population which was mainly A.gambiae. There were one or two hundred at each spraying in early July, one or two score at the end of that month, and none after mid August. In the same village the number of A.funestus, which was never abundant, were maintained through August and only fell away in September. In Ataraso A.gambiae disappeared as the country dried up, A.funestus tending to maintain its numbers. But as A.funestus was relatively common, mosquitos remained common in Ataraso till late September. The "indices" in Table 1, i.e. the total number of mosquitos per room, or per sleeper show the alteration in population in another way. The fall in the ratio gambiae and funestus is also instructive. In the village of Tomento, a few miles from Ataraso, A.gambiae predominated and funestus was never common. Room indices fell from 40 to 60 in early July to 10 in early August, and about 1 by mid September. All the preparatory work in the Tomento square mile was sacrificed as mosquitos had disappeared by the time the experiment could be carried out.

It is to be understood that during the period in which the counts of adult mosquitos were made in houses, the breeding places in the neighbourhood were discovered and visited at regular intervals.

5. CULICINE MOSQUITOS

There is a large and varied fauna of Culicines in West African forests, but it is remarkable how few attack man. In the course of several months work we were never bitten in the forest in day time, and Culicines resting in houses were extremely rare; for instance none were taken among the hundreds of Anophelines recorded in Table 1. We therefore made no observations on adult Culicines, but when larvae were found they were recorded (though not generally identified) and the effect of air spray on them was observed.

6. PROCEDURE IN THE FIELD

As soon as it had been decided that an area was suitable for a trial, it was mapped by a surveyor and the corners marked by felling trees.

It was then the duty of one of the entomologist sergeants to get to know the area in detail, marking down breeding places, digging artificial pools (but not cutting brushwood over them) and sinking water containers for Culicines to colonize. For artificial breeding places we used wooden boxes, 2 ft. square and eight inches deep, sunk flush with the ground, so as to avoid eddies. This provides a good big sampling area. We also used troughs cut from lengths of bamboo, generally about 1 foot long and two inches wide.

Catching stations were selected and studied twice a week (see above) both in the villages in the selected area and in more or less similar control villages a few miles away.

The day before the flight the sergeant entomologist and myself went over the ground, listing and numbering breeding places and assessing number of larvae. This was repeated 24 hours after the flight.

We were much interested in the possibility (reported from other parts of the world) that spray will kill nocturnal mosquitos (e.g. Anopheles) when in their day resting places. In order to get more direct evidence of kill of adult mosquitos in houses (it will be remembered that the structure of a house is generally very open) sheets were put down all over the floor of the catching stations just before the flight, and left till two hours after the flight, a careful lookout for dead mosquitos or other domestic insects being maintained. In addition Culicine mosquitos were bred from collected larvae put in small cages made entirely of wire gauze (34 gauge brass wire, 18 hole to linear inch; cylindrical cage, 6 inches high, 3 inches diameter) and exposed inside the houses. "Envelopes" (i.e. surfaces of filter paper) were also exposed in houses, flat on the floor and vertically on walls. In fact, as will be seen later, spray did not penetrate even these flimsy houses in quantity sufficient to kill Anopheles resting in them.

The next question was whether spray put down on a certain day would kill mosquitos in the succeeding night, as they moved about and touched sprayed leaves, thatch, etc. It was clear that if a great fall in adults was found, when catching stations were sprayed on the morning following the flight, (and this was always done), this could not be due to a larvicidal effect, and must be due to the mosquitos themselves picking up a dose during the night. In several experiments (first experiment at Ataraso, Natiem and Ntangufo) a great reduction in mosquitos was shown on the morning after the flight.

TABLE 1

Giving data for mosquitos caught in catching stations in certain villages. Table gives the number of rooms examined and the number of persons who slept in them.

Numbers of A. gambiae, females and males (G.F., G.M.) and of A. funestus (F.F., F.M.). No other mosquitos of any sort were collected. Table also gives the Room index (i.e. number of mosquitos of both sexes and species per room) and personal index (i.e. number per sleeper); also ratio of gambiae to funestus (based on the two sexes):-

Date	Room	Sleepers	Mosquitos G.F.	G.M.	F.F.	F.M.	Total	Indices Room	Personal	G/F.
					ATARASO					
18 Jly.	6	17	153	26	562	42	783	130	46	0.3
20 "	5	13	33	14	290	9	346	69	27	0.2
22 "	6	16	39	23	172	33	267	44	17	0.3
27 "	4	12	16	10	89	13	128	32	11	0.2
2 Aug.	6	15	24	5	323	20	372	62	25	0.1
5 "	5	10	4	1	133	14	152	30	13	0.03
9 "	6	16	7	4	206	43	300	50	19	0.04
12 "	5	14	4	5	49	1	59	12	4	0.2
16 "	3	6	1	1	125	22	149	50	25	0.01
18 "	4	8	1	1	124	14	140	35	17	0.01
23 "	4	11	0	1	95	9	105	26	9	0.01
29 "	6	13	1	0	45	10	56	9	4	0.02
3 Sept.	6	13	0	0	58	2	60	10	5	?
8 "	3	7	0	0	61	6	67	22	10	?
12 "	6	11	1	0	66	3	70	13	7	0.01
14 "	3	6	0	0	90	2	92	31	15	?
18 "	4	8	0	0	75	13	88	22	11	?

(figures after this date not comparable, owing to an air spray experiment)

APPENDIX C

ENTOMOLOGICAL REPORTS

by Prof. P. A. Buxton, F.R.S.

General accounts of "Prevalent Anopheles and entomological Procedure", and of "Types of vegetation in Area of Spray Trials" appear as Appendices B and A. They should be read with this appendix, to which they are in a sense introductory.

The results of the separate experiments follow. They have been arranged according to the type of spray liquid put down, and not in the order in which they were performed. If the dates are required, see Table A, page 3 of the main report. The experiments fall into the following groups:-

Oil, 1000 galls. pure DDT, 50 lbs.	Busua.
Oil, 1000 galls. pure DDT, 50 lbs.	Ataraso, second experiment.
Oil, 1000 galls. pure DDT, 250 lbs.	Natiem.
Oil, 1000 galls. pure DDT, 250 lbs.	Ntangufo.
Emulsion, 500 galls. pure DDT, 50 lbs.	Ataraso, first experiment.
Emulsion, 1000 galls. pure DDT, 50 lbs.	Awusiejo.
Emulsion, 1000 galls. pure DDT, 50 lbs.	Asani.

Summary of comparison of doses in ditches.

Certain acknowledgements are made early in the general report. It is a pleasure to give my personal thanks to Major K. O'Toole, R.A.M.C.; also to three entomologists, all of whom lived and worked in lonely places for many weeks, S/Sgt. R. A. Davis, Sgt. M. D. Froud and Sgt. G. W. Shield, R.A.M.C.; also to S/Sgt. W. J. Fairbairn, who collected nearly all the data from the experiment at Ntangufo.

ENTOMOLOGICAL REPORT - BUSUA

1. Description

To the entomologist the most interesting features were the mangrove swamps. There was one in the S.E. Corner of the area, containing much Avicennia in pure stand, the trees up to 30 feet high. Larvae of Anopheles melas were generally abundant (several per dip). The other area of mangrove lay between the river, the village and the road, with a small part of it on the East side of the road. Much of the Avicennia there was only 4 to 6 feet high, and the area was not on the whole a prolific breeding place of A.melas, though some larvae could always be found. We cleared a square of about one acre alongside the road and dug a number of small pits which were fully exposed to the sky. They were immediately colonized by A.melas and Culicines. There seemed to be no temporary fresh water and few swamps in the area, and no breeding of A.gambiae or funestus was found. Small numbers of A.cinctus, obscurus and hargreavesi bred in appropriate waters, but were never found in houses.

Sampling of adult mosquitos in six sleeping rooms in Busua village had gone on twice weekly from Aug. 16th. The only Anopheles taken were melas (that is to say they were members of the gambiae group, generally dark and with four bands on palps, and they all appeared to come from the brackish Avicennia swamp.

Larval characters supported the diagnosis of melas). The room index (based on all mosquitos) was falling through August and September (see below).

Among Culicines, one noted small numbers of Aedes aegypti (the yellow fever mosquito) in the village. In our experience this insect only occurred in villages along the coast. We have never seen it inland.

Breeding of Culicines was increased by setting out boxes (area 2 ft. x 2 ft.) and bamboo troughs.

A rain gauge was maintained in Busua during the period of the investigation. For September the rainfall was 1.65 inches, 13 rain days. The corresponding figures for Takoradi and Axim were:-

Takoradi 0.79 inches, 12 rain days.

Axim 2.44 inches, 16 rain days.

It is probable that August had been even drier at Busua.

About half of the Busua area was under maize and cassava. The rest of the area was all dense secondary forest, much of it about 30 feet high, and so thick at ground level that one could only pass through by using a cutlass. There was no primary Evergreen Tropical Forest.

The area and the surrounding villages were intensively studied by an entomologist, Staff Sergeant R. A. Davis, R.A.M.C. who resided in Busua from early August until several weeks after the air spray.

2. Effect on Larvae

The following results were obtained, on breeding places of different types. An. and Cu. refer to the number of Anopheline and Culicine larvae in ten dips. Contamination is in mg. of pure DDT per sq. metre, data supplied by P.S. from envelopes exposed alongside the breeding place, generally three at each place. A "trace" is less than 0.1 mg. of DDT per sq. metre.

Ref.	Type of Place	Contamination	Results
	Mangroves		
1	Cleared mangrove, pits open to sky, to An. 50 Cu.	3.2	Complete destruction An. and Cu. None 4 days later when springtide flooded area. 5 days after spray, 1st and 2nd stage Anopheles larvae and plenty Culicines.
2	Under Avicennia trees, 40 An.	0.8	95% kill by next day. Many larvae present 5th day.
3	Ditto. Close to 1. Heavy but irregular shade, 4 An.	1.2 to 1.8	All killed by next day.
2A	As 3. 10 An.	0.5	No kill.
5	Small stream under Avicennia 1-2 An.	0.1 to 0.2	No kill, but very few larvae at start.
	Dense Shade		
4	Grassy pool in forest 1 An. Obscurus, 9 Cu. Box a few yards away, 6 Cu.	0.6 0.003	Complete kill by next day. No kill.
	Dense shade, rather open at side, close to road.		
7	Pool in wood. 1 An. obscurus 18 Cu.	0.3 to 0.6	One An. next day. 7th day many Cu.

Ref.	Type of Place	Contamination	Results
11	Stream in similar place 10 Cu.	Trace 0.8 (2 cards within 1 yard)	1 Cu. next day.
	Partial Shade		
6A	Debris in stream 6 An.	0.1	No larvae next day (but original numbers very low).
8	Debris in stream 5 An.	0.1 or less	No larvae next day. 6th day 2 An.
9	Debris in stream 2 An. Many Cu.	Trace	Slight reduction.

In considering these results it has to be remembered that under dense shade the distribution becomes very erratic (see breeding places 4 and 11 above). A small breeding place may, therefore, be entirely missed by spray, or receive such a minute amount as to produce little or no effect. The results with streams are still more erratic. One of us had been a forest stream the surface of which was red with coloured oil which had been held up by floating debris; beside it was a card showing almost no deposit; i.e. the visible deposit on the stream had floated down from an area where the forest was less thick. This might be a point of considerable importance in an area such as Burma, Malay Peninsula or the Phillipines where important species (A.minimum and maculatus) breed in streams. Air spray falling on the stream at some points might control larvae at many other points, being carried downstream, spreading as it went.

The facts tabulated above justify one in saying that if the deposit beside the breeding place is 0.8 mg. per sq. metre or over, all larvae killed, if it is about 0.5 or 0.6 mg. the kill may be high or low, if it is under 0.2 mg. there is no kill. It is realized that an effective figure of 0.8 mg. per sq. metre is remarkably low, even in comparison with certain laboratory results. The amount is moreover, we understand, on the border line of what can be estimated by the envelope method; it may, therefore, be that this figure is not very precise. We claim, however, that it was carefully established in several spots. The anomaly may disappear when more is known of factors causing DDT on water to cease to kill larvae. At present results on its persistence are conflicting.

It is interesting to consider what might have occurred, had the same volume been sprayed at Busua, but containing 3.0% instead of 0.6% pure DDT. We should presumably have a complete kill in breeding places 2A, 7 and probably 11 (so far as can be predicted for streams); we might or might not have had complete kill in 5. It seems clear that an increase in concentration of DDT would be well worth considering.

Certain casual observations are perhaps worth recording. There was evidence that water skaters, water boatmen, mayfly larvae, prawns and copepods were not killed by the dosages applied. Coconut shells near the village contained live larvae after the air spray though the dose falling on flat ground in that area was certainly high. It is possible that the shape of an open shell (or of a bamboo trough) standing up above the ground, causes spray to drift past it and miss the water surface.

3. Effect on Adult Mosquitos

The houses in Busua are extremely well built, (in contrast to Ataraso, Natiem, etc.). The walls carry right up and make a close fit with the roof, the triangular gable is closed, roofs are galvanised iron (in most cases), window spaces and doors are framed and shut at night. The rooms are ceiled with poles and mud. If one goes inside a sleeping room by day, hardly a chink of light can be seen anywhere.

In the six catching stations, all of this type, we put sheets on the floor before the air spray, and put down three envelopes and one wire gauze cage of adult Culicines in each. Most of the envelopes received a "trace" of deposit (i.e. under 0.0006 mg. of pure DDT per sq.m.), but the caged mosquitos were not killed and no dead mosquitos fell on the sheet. (There were, however, only about two per room at the time of the flight.)

We also carried out work in five more open structures:-

(a) Living room in village; open door and window at each end and wind blowing freely through, enough to rustle paper. Three cards horizontally on tables, "trace" on each.

(b) Similar living room, three open windows and one open door. One card 0.198 mg., two others "trace".

(c) Small detached kitchen. One gable open (6 x 3 x 3 ft.) no ceiling, door open, cards on floor, "trace" only.

(d) Old church, galvanised iron roof in good order, west wall (windward side) completely down, other three walls pierced by large unglazed windows, Cards on floor 1.4, 0.8, 0.7 mg.; card pinned vertically on woodwork 0.1 mg. One cage of adult mosquitos, none killed.

(e) Wooden "Army" hut, good roof and walls, one open door, windows on all sides, screened by wire gauze. Cards on floor, "trace" only. Cards outside, away from shelter 2.2 mg. One case of mosquitos in hut on table under window, not killed.

It seems clear that, in spite of wind, air borne spray is very erratic in its penetration, even of these open buildings.

Six sleeping rooms in Busua had been in regular use as catching stations for some weeks before the trial. They were examined twice weekly, sheets being put down and mosquitos collected by flitting. The following figures give for certain dates in September, the total number of mosquitos and the A.melas in the six rooms, the balance are nearly all Aedes aegypti.

		Before				After	
Busua	Sept.	2	6	13	20	28	Oct. 3
	Total	29	50	40	15	10	10
	A.melas	27	31	24	5	4	5

Our best control is Butre, a coastal village near a mangrove swamp, two miles from Busua. In Butre (6 sleeping rooms) there are considerable numbers of A.funestus, which have been excluded from these figures; members of the gambiae group are recorded as melas which seem reasonable in view of local circumstances.

Butre	Sept.	5	12	19	29
	Total	148	132	86	60
	A.melas	111	98	71	45

In view of the small numbers of mosquitos in Busua at the time of the flight, and of the steady fall in melas and domestic mosquitos in Butre, one is not justified in concluding that the air spray at Busua was responsible for the fall in numbers of mosquitos.

An attempt was made to study the lasting effect of DDT on vegetation. Coarse grass was picked outside the Army hut, where cards had recorded a deposit of 2.2 mg. pure DDT per sq.m., a heavier deposit than the average. Samples of grass were picked one hour after the flight, also five days later, and put in clean paper bags. Ten adult Aedes a few days old and fed on syrup were put into each bag, and left 24 hours. There were only one or two deaths in each and in control. The result is astonishing, for the grass was liberally splashed with red stain. It seems possible that DDT in oil is rapidly absorbed into certain green leaves, a point which should be investigated at Porton.

Another possibility, that 10 mosquitos put in a bag full of grass for 24 hours all sat on the inside of the bag and not the grass seems so unlikely as to be hardly worth consideration.

ENTOMOLOGICAL REPORT ON SECOND EXPERIMENT AT ATARASO

4. Description

Since the first trial here (Sept. 20th) there had been very little rain until a few days before the experiment. Rain gauge figures from Abra, eight miles away, showed only 0.44 ins. (eight rain days) during the first 14 days of October. Several of the natural breeding places in small forest streams had dried up. The swamp described in the first report, ½ mile from Ataraso village, was still the only breeding place of A.funestus in the area.

The breeding places were examined on the morning following the trial, and again next day.

The amount of spray reaching the ground was measured by "envelopes", three being set out close to each breeding place.

No cages of adults were put out in the houses, and no sheets were put down. The negative results obtained here before, and confirmed at Busua and Natiem were taken as a sufficient proof that adults were not killed inside houses.

5. Effect on Larvae

The following table is a summary of the results:-

Map. Ref. No.	Type of Breeding Place	Amt. of DDT in mgms. per sq. metre Average	Range	Condition few hours before Trial	After 24 hours	After 5 days
5	Swamp, amongst tall grass and ferns.	0.5	Tr to 1.1	1 - 2 An.fun. a dip	No change	No change
10	Swamp, with scant grass fairly open.	0.8	No variation	2 - 3 Anophs. a dip	1 Anoph. in 10 dips	No further change
1	Box, under high virgn. forest, cover 8/10	0.1	Tr - 0.1	Average 4 larvae a dip	Av. of 1 larvae a dip	No larvae
18	Box, under bamboo cover 8/10	0.1	No variation	Av. 3 larvae a dip	No larvae in 10 dips	No further change
15	Box, in damp soil, at edge of clearing	0.8	No variation	5 larvae in 10 dips	No larvae in 10 dips	No further change
17	Box, in secondary forest, cover 7/10	0.5	No variation.	Av. 3 larvae a dip	2 larvae in 10 dips. 2 dead larvae	No larvae
22	Box, in secondary forest, cover 8/10	0.6	0.2 - 0.7	15 - 20 larvae a dip	No larvae in 10 dips, 8 pupae alive	No change
16	2 bamboo troughs below small bamboo.	0.1	Tr - 1.4	Abundant Culicine all stages	No change	No change. Many pupae
19	3 bamboo troughs below dense bamboo.	1. 0.1 2. Trace 3. Trace	-	Abundant Culicines all stages	No change	No change. Some pupae

The result shows that, as elsewhere, the larvicidal effect of the spray was erratic. In particular one notices that in the swamp, larvae of A. obscurus in the more open parts were killed, those of A. funestus among grass and ferns were protected. The very irregular distribution of spray is shown by figures from different envelopes at the same spot. For instance at position 1, envelopes within a few yards of one another received a trace to 1.1 mg. of DDT, a range of over fifty fold.

The complete kill in three boxes in secondary forest, 20 - 30 feet high, and very thick, but penetrable without a cutlass is remarkable; so is the kill of Culicines in box 18 which received a low dosage.

We also set out, as at Natiem, pairs of soup plates, in each of which 10 freshly caught larvae of Anopheles were placed without mud or weed. All were placed at position 23 on map. The results were as follows.

Position	Amount of DDT on Envelope; mg/sq. Metre	Before Trial	24 hours later
In open	2.3	12 larvae	All dead
In tall grass	1.2	20 "	7 alive
In grass	0.3	10 "	All dead
Heavy cover banana trees, etc.	Tr to 0.2	20 "	3 alive
Dense corn	0.2	20 "	3 alive

The lack of relation between kill and dosage (particularly the survival of 7/20 larvae in a plate receiving 1.2) is remarkable. Even more remarkable, by previous standards, is the death of most larvae receiving a still lower dosage.

6. Effect on Adult Mosquitos

The following table shows the number of mosquitos collected per room before and after the trial; they were all A. funestus.

OCT.	2nd	5th	10th	13th	16th	19th	21st	24th	28th
ATARASO	10	6	11	8	10	11	4	7	10
MPANANGAZA (on edge of area)	17	15	9	7	7	13	22	5	6
ASUBOI (control village)	8	5	7	7	9	20	16	5	6

After the trial there was a 100% increase at the edge of the area and in the control village one mile down wind, while at Ataraso the level remains the same and then drops.

The situation was complicated by a festival a few miles away, which drew away many of the people; one knows that this would at once reduce and disturb the number of Anopheles resting in bedrooms.

The work at Ataraso was carried out most thoroughly and efficiently by Sergeant M. D. Froud, R.A.M.C.

7. Description

The village of Natiem (or Ndetiam) is at the centre of the area sprayed which was approximately a mile square and bisected by the main Axim-Takoradi Road. Four other villages Amanboajo, Asesure and Mpeniasa are situated within the area and catching stations were established since June In Natiem, Amanboajo and Asesure. The country consists of low hills and swampy valleys, for the most part covered in a dense, but fairly low secondary scrub (Type 'B' "TYPES OF VEGETATION IN AREA OF SPRAY TRIALS"). There are occasional patches of cultivation on the hillsides cassava and maize being the main crops, and a large rice field was situated in the floor of one of the valleys. A certain amount of permanently wet Freshwater Swamp Forest occurs to the North West of the village of Natiem, and a further roadside continuation of the same swamp is densely clothed in ferns between 2 and 3 feet high but is otherwise kept clear under the road maintenance scheme. Some high secondary forest is found on the higher land to the West and South of the area.

8. At the time of flight all the swamps, with the exception of the small permanent freshwater swamp forest and its continuation were dry. The forested area of this swamp could not be shown to be breeding mosquito larvae, a suggested possible reason is that the large amount of flocculent iron precipitate in the water might render it unsuitable, though a few culicine larvae were found on several occasions in the ferny areas alongside the road.

9. There are two main streams within the area; the Asesure Stream near the village of that name, and another to the East of Natiem with two tributaries. During the wet season (June to August) these were flowing well and formed breeding places of A.obscurus, A.funestus, A.cinctus and many species of Culicine, either in the stream or in side pools associated with it. At the time of the spraying however they were rapidly drying and for the most part consisted of discontinuous muddy pools in an otherwise dry stream bed. These pools formed the majority of natural breeding places numbered just prior to the flight and contained small numbers of A.funestus, A.obscurus and Culicines.

10. The portion of the Natiem stream South of the road was still flowing slowly. With the drying of the roadside pools and the increase in shade in the rice swamp the gambiae index dropped to almost NIL by the end of August, but the funestus index, which was not so dependent upon temporary pools had only dropped to approximately 10 by the end of August and remained in the region of this figure during September and October until the day of flight.

Ten natural breeding places were observed on the day before the flight, and an estimation of the mosquito fauna was made by counting the number of mosquito larvae found in a given number of dips. (TABLE 1.)

11. These natural breeding places were supplemented by twelve dishes each containing 10 larvae of Aedes aegypti the dishes being so placed in the field that some were in the open, others under many different types of bush (TABLE II).

12. On the day of the flight sheets were placed in the bedrooms in Natiem that were normally used as catching stations so that any immediate kill in situ due to the DDT spray might be observed.

13. The houses in Natiem are very flimsy, with walls of small poles and spaces between them. In addition there is usually a fairly large gable space between the side walls and the roof through which spray might drift. To observe the effects of spray upon the mosquitos in and around houses ten cages of Aedes aegypti (about 20 - 30 mosquitos to a cylindrical cage of mosquito screening 3" diameter by 6" high) were placed inside houses and any deaths after the flight were recorded.

14. Normal house catches were discontinued in the villages within the area from the weekend before the flight so that no residual effect of pyrethrum spray might affect the experiment. These catches were resumed the day following the flight.

15. As controls to the experiment similar catches were made over long periods in villages around the area as similar as possible to those within. For this purpose the village of Aguafo and Ewuku to the South of Ndetiem, Nsain to the West, and Dadjwin to the East were used.

Results and Conclusions

16. In the form, quantity and concentration used it is obvious that the spray did not ensure a larval kill under anything but light types of cover (TABLE I). Earlier in the year the spray would almost certainly have proved effective against the larvae of A. gambiae which breed in much more open situations. These conclusions are amply supported by the evidence obtained from the artificial breeding places, (see TABLE III) and from previous experiments elsewhere. We feel that information from streams is very unreliable, for we have observed the oil carried down and spreading to spots where cards showed that no local fall of spray had occurred.

17. The adult results are more exciting. To the entomologist on the morning after the day of flight the chief of Natiem said "Ah Massa! My people make complain. There be no mosquito at all, everyone get fine fine sleep! Villagers are perhaps even more inclined than other people to allow their hopes to influence their views of life, but there was some ground for what they said. Before the air spray we had consistently been getting an index of 10 to 20 mosquitos per room in Natiem; this had gone on steadily for more than a month. After the spray the figure fell to under two and remained there for a clear 12 days (TABLE II). Amanboajo and Asesure showed the same thing, the latter village being not very significant as it was so small that only two rooms could be sprayed.

18. The four control villages of which three had been studied for a long time showed no sudden fall at about the spraying date, though there is a slight fall in index as the country dries up. They were appropriate as controls, for all these seven villages fall within a three mile circle, are at about the same altitude, and at this season some 90% of all mosquitos in houses were A. funestus.

19. The information in Table II is so interesting that though the conclusions seem self evident it has been felt worth while to test their significance statistically. Mean room indexes were worked out for three periods (a) before spray, (b) period shortly after spray, Oct. 12th to 23rd, (c) Oct. 25th and later. The significance of the differences between means was worked out by the "t" test. Thus for Natiem one has

period a, 8 observations, mean 12.4

" b, 3 " " 1.6

" c, 2 " " 6.0

The test shows that the difference between the first two periods is very highly significant (P close to 0.001), and that between the second and third significant by conventional standards (P is over 0.01). The same two differences (between periods a and b, and b and c) are significant for Amanboaji, not for Assesure. Both differences are significant if one takes the results for the three sprayed villages together. Similarly, figures for control villages separately for the two pairs of periods do not differ significantly; nor is the difference significant for the two control villages taken together.

20. A further point comes out in the analysis. A very cautious student of TABLE II might point out a tendency for control figures to fall between periods a and b, and might suggest that the greater fall in treated villages could also be due to natural events and not to spraying. This view is shown to be untenable, for the mean room indices of the treated and control villages do not differ significantly before the spraying, (period a), but the difference is significant (P is greater than 0.02) afterwards.

One may sum up one's conclusions on TABLE II as follows:-

(1) The spray reduced the mean room index of Natiem from 12.4 to 1.6, i.e., over 85%.

(2) The population of mosquitos in the houses was held down to about that figure for about 12-14 days.

(3) Recovery of population is noticeable by the 17th day.

(4) Data for 3 sprayed villages are consistent with one another. They differ to a marked extent from figures from unsprayed controls.

21. The recovery of the mosquito population by about the 14th - 17th day raises a point of interest. It is not easy to see why a substance so stable as DDT, having been successfully laid down, should cease to be effective. It seems that this cannot be attributed to evaporation, or atmospheric moisture, or (so far as is known) to the long ultra-violet which reaches the earth's surface. It seems possible that the oil and DDT might be washed off certain surfaces by heavy rain. We have no data from Natiem, but the following readings were made at Axim, only 4 miles away.

October	11	12	13	14	15	16	17	18	19	20
Rain (inches)	0	0	1.18	0.01	0.02	0	0	0.10	0.10	0.39
	21	22	23	24	25	26	27	28		
	0.02	0.12	0.95	0	0.17	0.04	0.16	0.04		

We cannot learn much from these figures. The effect of DDT was greatly reduced between 23 and 28th October. There was heavy rain on 23rd (but there had been heavier on 13th). Another possibility is that DDT in oil may be absorbed by green leaves and so put out of action. But if that is so, the absorption must occupy many days, contrary to what was thought to occur at Busua (see Entomological report on Busua, above).

22. Adult culicines were not killed in cages (TABLE IV) even on verandas; on some the dosage of DDT on the card on which the cage was stood was obviously lethal, and this seems to indicate that the cage is interfering with the accessibility of the mosquitos to the spray. Simple tests with a flit gun show that in a breeze much spray is carried round or over a cage. Some, however, does fall inside, and some is held on the windward and leeward wall. Evidence from gauze cages in a wind should therefore be accepted with caution. On sheets inside houses, and in cages in the same houses, no deaths occurred. This is consistent with earlier observations (Ataraso 1st trial, see below), and is noteworthy in view of the flimsy nature of these houses.

23. It is of interest to note that although no counts or experiments were made, no evident effect could be noticed upon the numbers of larger insects in the bush the day following the spraying. Butterflies, grasshoppers and beetles remained numerous and appeared to be quite unaffected.

24. The results owe a great deal of their value to the work of Sergeant G. W. Shield, R.A.M.C.

TABLE I

RESULTS: A. LARVAL (X) NATURAL

In this and subsequent results Trace DDT means less than 0.1 mgs. pure DDT/Metre^2

Map Ref. No.	Description of Breeding place	Strength pure DDT in mgs. per sq. metre		Larval catch day before flight	Larval catch day after flight	Larval catch 8 days later
		Average	Range			
1	Edges of a slowly moving stream, overhanging banks, otherwise fairly open 50% cover.	3.1	0.2 - 10.2	10 An. in 10 dips	Nil in 10 dips	Nil in 10 dips
2	Edges of forest stream amongst grass and debris. Fairly heavy shade, but stream running.	13.8	Uniform	4 An. in 10 dips	Nil in 10 dips	Nil in 10 dips
3	Edges of forest stream. Fairly heavy cover, 90% but stream running.	0.4	0.1 - 0.7	3 An. in 10 dips	Nil in 10 dips	Nil in 10 dips
4	Clear water shaded by grass open to sky. Floating veg. present.	26.1	20 - 51	3 An. in 10 dips	Nil in 10 dips	Nil in 10 dips
5	Pool shaded at sides but fairly open to the sky.	1.57	0.3 - 2.4	1 An. in 10 dips	Nil in 10 dips	Nil in 10 dips
6	Shady muddy pool. Waterlilies, roots and debris in water. 80% shade but open from North side.	0.31	Trace - 0.8	2 An. in 30 dips	1 An. in 30 dips	Nil in 30 dips
7	Shady pool. No aquatic vegetation. Roots at side of pool. 90% cover of 30' scrub.	0.9	0.4 - 1.2	13 An. 1 Pupa in 20 dips	1 An. 1 Pupa in 20 dips	Nil in 20 dips
8	Muddy pool with roots at edge. 90-100% cover of dense 20' scrub.	Trace	Uniform	7 An. 1 Cul. in 40 dips	5 An. 6 Cu. in 30 dips	1 An. in 30 dips
9	Densely shaded pool, 100% cover. No aquatic veg.	Trace	Uniform	1 An. 1 Cul. in 30 dips	3 Cul. in 30 dips	Nil in 30 dips
10	Ferny swamp. Water 100% shaded by heavy cover 2 - 3' high.			1 Cul. in 30 dips	Nil in 30 dips	Nil in 30 dips

Area very dry.

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TABLE II (PART 1)

RESULTS OF COUNTS OF ADULTS, OF ADULT MOSQUITOS, IN NATIEM AND OTHER VILLAGES IN AND OUTSIDE SPRAYED AREA
VERTICAL LINE INDICATES DATE OF SPRAYING. INDEX IS TOTAL MOSQUITOS/NO. OF ROOMS SPRAYED (GENERALLY SIX)

A. INSIDE SPRAYED AREA

										:					
NATIEM	Date	Sep. 5	8	13	21	25	29	Oct. 4	7	:	Oct. 12	17	23	28	Nov. 1
	Total Mosq.	61	72	65	54	62	89	120	72	:	9	11	9	37	37
	Index	10	12	11	9	10	15	20	12	:	1.5	1.8	1.5	6	6
AMENBOAJO	Date	Sep. 1	8	12	20			Oct. 4	6	:	12	17	19	25	Nov. 1
	Total Mosq.	52	43	150	51			65	28	:	4	7	2	20	29
	Index	13	11	37	9			16	7	:	1.0	1.7	0.5	5	7
ASESURE	Date	Sep. 1	7	12				Oct. 4	6	:	12	17	19	25	Nov. 1
	Total Mosq.	34	14	78				27	5	:	4	4	5	3	15
	Index	17	7	39				13	2.5	:	2	4	2.5	1.5	7

B. CONTROL VILLAGES, NOT SPRAYED

EWUKU	Date	Sep. 6	12	18	27	Oct. 3	5	13	20	24	30	
	Total Mosq.	94	44	36	38	100	36	29	24	22	75	
	Index	16	7	6	6	18	6	6	4	4	12	
AGUAFU	Date	Sep. 5	14	18	26	Oct. 2	5	13	20	24		Nov. 2
	Total Mosq.	41	54	79	38	67	29	45	55	13		61
	Index	7	9	13	6	13	5	7	9	2		10
NSAIN	Date					Oct. 10	16	25				
	Total Mosq.					80	22	26				
	Index					26	5	4				
DADJWIN	Date	Sep. 11		22		Oct. 16	21	25	31			
	Total Mosq.	233		194		114	40	38	44			
	Index	39		32		19	7	6	7			

TABLE III

Results from soup plates containing larvae of Aedes exposed under different types of cover

Vegetation	Percent of sky covered	Number of Plates used	No. of larvae before flight	Percentage of living larvae 24 hrs. after flight
Open	0%	1	10	0
Grassy	10 - 20%	2	20	0
Tall herbs	40 - 60%	5	50	42
Thick bushes up to 20 ft.	80 - 90%	4	40	87

TABLE IV

Results of spray on caged Adults or Aedes Aegypti (20 - 30 Mosquitos per cage)

Site	No. of cages used	Estimate of pure DDT in mgs. per sq. metre on cards beside cages		Resultant kill within 24 hours
		Average	Range	
Open - centre of village	1	8.5	Uniform	Nil
Open verandah (windward)	1	4.3	2.6 - 5.3	Nil
Open verandah (leeward)	1	5.4	2.0 - 7.2	Nil
Inside bedroom on floor	7	Trace	0.0 - 0.1	Nil

ENTOMOLOGICAL REPORT, NTANGUFO

Introduction

25. The results obtained against adults at Natiem were so promising as to demand confirmation. No area which had been carefully studied had an adequate number of mosquitos, and it was therefore decided to look for a village which gave good house counts and was suitable for spraying and control purposes, even if the entomological history of the area was not known, and the breeding places not studied.

Site

26. S/Sgt. W. J. Fairbairn, in charge of the anti-malaria control at Takoradi, investigated certain villages outside his controlled area. He found us an area of about one square mile round the villages of Ntangufo and Kansawurado, and this area was selected for the trial. Two other villages, Anaji and Anaji Junction were situated about a mile upwind of the area, and were used as controls. The area is mainly covered with dense secondary growth of fairly recent origin, interspersed with patches of cultivation, mainly cassava and coconuts. There is no primary forest. The main breeding places are large roadside pools along the old Takoradi-Sekondi road, and a swamp at the upwind edge of the area.

Sampling

27. No physical sampling was attempted, nor was any attention paid to the effect of the spray on larvae.

Entomological Results

28. The following figures give the total number of mosquitos in the rooms sprayed, and the index (i.e. number per room); nearly all mosquitos were A.funestus.

Village	Oct. 25	30	Nov. 3	4	7	10
Ntangufo			SPRAYED			
Total	-	173		56	5	22
Index	-	43		5	0.8	2.2
Kansawurodu						
Total	-	252		63	2	7
Index	-	25		6	0.3	1.9
Anaji			CONTROL			
Total	280	35		49	146	70
Index	47	9		8	29	14
Anaji Junction						
Total	269	48		132	62	52
Index	67	24		33	31	13
N. + K. Index	-	30		5.7	0.6	1.5
A. + Aj. Index	55	14		18	30	13

29. It will be remembered that the first two villages were in the sprayed area, the last two were upwind and are the controls. At first sight one notices a reduction of index in sprayed villages from 25 or 43 to 5 or 6, and then lower figures on later dates. But one is compelled to be cautious, observing that:-

1. Only one (or two) counts were made before spraying, so that it seems unlikely that a statistical test would give help.

2. The indexes in the controls, especially in Anaji are very far from steady.

It seems justifiable to add the results for the two sprayed villages (N + K), and two controls (A + A). Inspection then shows that there is an immediate reduction of over 80%, followed by a greater reduction in a few days in sprayed villages, but none in unsprayed. One feels justified in accepting this as confirmation of the work at Natiem, indeed the results are closely similar. If the figures for Ntangufo and Kansawarodu had stood alone it is difficult to know how much "significance" could have been attributed to them. The figures seem to indicate that the spray was still very effective a week after it was put down. No further observations were possible.

30. Description

The Ataraso area had been studied for a long time and was very familiar to the entomologists. Even during the rains of July Anopheles funestus had been commoner than A.gambiae in house counts, and during the August drought A.gambiae disappeared, and none had been seen for several weeks before the day of the flight. Owing to lack of rain, there was only one breeding place of A.funestus within the square mile. This was an open swamp, without trees, carrying a dense cover of sedges, and a considerable number of broad leaved Aroids, and Scitamineae. This vegetation was 3 to 4 feet high and almost concealed the water surface from above except at one or two points. The swamp was of about two acres, half a mile from Ataraso village. There were also two small streams heavily shaded in places, but partly open to the sky (5/10ths cover).

On such a stream it is known that droplets of DDT in oil may be carried a long way. In them were small numbers of larvae of A.obscurus and another species.

In addition, artificial breeding places were put out, which became colonized by Culicines before the test. Some were troughs cut from large bamboos, but the best were shallow wooden boxes, two feet square (i.e. sampling a considerable area); these were dug in with the top flush with the ground to avoid eddy effects.

None of the breeding places, natural or artificial was fully exposed to the sky.

The adult mosquitos had been studied twice a week for some two months before the trial by using "catching stations". All villages, both those sprayed, and the controls contained A.funestus only and were at the same altitude and no more than 2½ miles from one another.

The houses in this area have mud walls and a thatched roof. The gable at the end of the roof is left completely open, and forms a triangular hole about a yard high (see photos. Nos.13 and 14) at each end of the house. Sleeping rooms have an imperfect ceiling of matting. An air spray has therefore every chance of drifting into the room.

31. Effect on Larvae

The following results were obtained from the breeding places:-

Type of Place	Result
Box, 10 yards from river under high virgin forest; cover 8/10. Culicines.	No kill up to 23 hours or 5 days.
Boxes (3) in secondary forest about 20 - 30 feet high, very dense, but penetrable without a knife. Culicines.	In two boxes, no kill in 24 hours. In one box kill of 95% of hundreds of larvae. 5 days later numerous larvae in this and other boxes.
Pools (5) in forest streams, partly in dense shade, but occasionally open to sun. Anophelines, under 1 per dip.	No kill in 24 hours, in 3 places. 80% reduction in two. 5 days later, Anopheline larvae in all places.
Pool, isolated and stagnant in secondary forest, as described for boxes.	No kill in 24 hours. Active breeding 5 days later.
Swamp, described above. Anopheles funestus, 1-2 per dip.	No kill in 24 hours. Active breeding 5 days later.
Bamboo troughs (3) placed under dense cover of clump of bamboo 50 feet high. Little ground vegetation.	No kill in 24 hours. Active breeding 5 days later.

It is evident that the larvae were killed in 24 hours in some spots, not others. If the position of the breeding places on the map is considered, the results seem erratic, neighbouring spots giving inconsistent results.

There was slight rain on several days after the test. This did not wash the DDT emulsion off leaves and other vegetation, so as to give a delayed kill. This seems to be important.

For technical reasons it was not possible to stain this emulsion spray and consequently a precise estimation from cards was unobtainable. A rough estimate was obtained from plain glass plates, three at each breeding place. There seemed to be little correlation between this and the kill of larvae.

32. Effect on Adult Mosquitos

In Ataraso we covered the floor of 5 rooms in which people had slept, with white sheets before the flight. These were watched by a European Sergeant (entomologist) till an hour after the conclusion of flying. Only one Culicine, 3 small flies and 4 ants fell dead on the sheet, though there are reasons for supposing that there were 60-90 A. funestus resting on the walls or under the thatch of the five rooms. None of the Culicines in wire gauze cages (one in each of 5 rooms) died within 24 hours. It seems clear therefore that the spray did not drift in and kill mosquitos in the houses (in spite of the large gable openings).

What difference was found in number of mosquitos recovered by flitting houses, on days before the flight, and on the day immediately after it (20th September)?

The following figures give total A. funestus collected per sleeping room and the number per room on certain dates before and after the flight.

Ataraso

Date	Sept. 3	8	12	14	18	21	25	28	Oct. 2	5	10
Total Mosquitos	60	67	76	92	88	18	70	39	49	19	66
Room index	10	22	13	31	22	4	12	8	10	6	11

Animakrom

Date	Sept. 13	18	21	25
Total Mosquitos	77	78	27	37
Room index	38	39	13	18

SPRAYED

Mpanangaza

Date	Sept. 12	14	18	21	25	28	Oct. 2	5	10
Total Mosquitos	152	59	102	65	59	36	88	88	44
Room Index	30	20	17	11	12	7	17	15	9

Asuboi (Control)

Date	Sept. 3	8	12	14	18	22	25	28	Oct. 2	5	10
Total Mosquitos	38	59	43	171	51	76	61	33	40	27	38
Room Index	6	20	7	24	9	15	10	6	8	5	7

In considering these figures one pays most attention to the room index, (because the total mosquitos is influenced by the number of rooms, which was not constant). The control village, Asuboi, was a mile upwind from the sprayed area; the room index is erratic, but with no trend, and no considerable fall at the time of the spray (20th September). In Ataraso, in the centre of the sprayed area indexes had run from ten to twenty-two for some weeks, with a tendency to rise; on the morning after the spray the index fell to four, much the lowest recorded figure. Mpanangaza on the upwind corner of the sprayed area, and Animakrom, on the downwind corner, show considerable falls in indexes following the spraying.

I think that one is justified in regarding the fall at Ataraso as significant, for it amounts to an 80% reduction, but it is not easy to say how long the effect lasted. In the two corner villages, Mpanangaza and Animakrom, there is some fall, which would not by itself be regarded as due to the spray. The whole story seems consistent, and to give strong support for the view that an 80% reduction in the centre of the area was due to the spray.

The reduction of mosquitos in Ataraso cannot be due to the effect of the spray as a larvicide, for it has already been shown that in the swamp, the only breeding place of A.funestus, larvae were not killed; moreover the reduction happened within 24 hours of air spraying.

ENTOMOLOGICAL REPORT: AWUSIEJO

33. Description

Awusiejo had not been studied for long. Early in October, when villages on which we had worked since June or July were dry and quite without mosquitos, it was found that Awusiejo held large numbers of A.funestus and that they bred in a few swamps. Some were of a familiar type with sedges at the margin and waterlilies where they were more open. Others were too deep for a man to go into (quite apart from the crocodile question), thick with Pandanus and covered with the floating plant Pistia.

There were no temporary waters, and the total number of breeding places was small. Records of rain gauges at Takoradi and Busua (both within eight miles in different directions) are as follows, for the period 1 - 21 October:-

Takoradi rain 1.18 inches, rain days 6

Busua rain 1.55 inches, rain days 8

By tropical standards one may say that the weather had been dry.

No artificial breeding places were put out and no attempt was made to see whether spray drifted into houses, as previous work had shown that it did not do so in sufficient quantity to kill insects.

34. Effect on Larvae

The larvicidal effect of spray was studied in eight places. The number of larvae (Anopheline, and presumably A.funestus except where the contrary is stated) is given per 10 dips. There is no quantitative record of dose of spray, as the emulsion could not be stained. Glass plates showed that spray fell round all breeding places.

The results, given below show a rather erratic effect of spray. In most places, a large proportion of larvae were killed, even if there was some cover from trees (8). Failure to give complete kill in the open borrow pit (1) in the centre of the area is curious.

Map Ref.	Place	Day Before	One Day After
1	Borrow pit, grassy edges, rest quite exposed.	9	2
2	Edge of large swamp. Palm and Pandanus overhead. Pistia on surface.	3	0
6	Grassy swamp, bush at side, no trees overhead.	50	0
7	Similar.	25	2

Map Ref.	Place	Day Before	One Day After
8	Swamp with grass and water lilies, in low forest, some trees overhead.	10	3
9	Pool full of rusty precipitate, ferns at side, open above.	60 Cul.	4
4	Swampy stream grassy edges, slight overhead cover.	6	0
5	Similar.	1	1

35. Effect on Adults

Of all mosquitos taken in catching stations at Awusiejo about 98% were A. funestus, the remainder A. gambiae. Six rooms (in which a total of 9 to 11 people slept) were sprayed on each occasion, and gave the following number of mosquitos:-

Date:	Oct. 6	17	23	27
Total Mosq.:	204	122	88	67
Room Index:	34	20	15	11

These figures give no evidence that the spray reduced the mosquitos, the numbers of which were in any case falling, as they were elsewhere, before the experiment; one observes the following percentage reduction:-

From 6 to 17th October	40%
From 17 to 23rd October	27%
From 23 to 27th October	24%

That is to say, the rate of loss was nearly the same in the period before and after the experiment.

The control village for Awusiejo was Hautapo, about a mile away upwind, outside the spray area. The figures do not seem to be of great interest, but are as follows:-

Date:	Oct. 17	23	27
Total Mosq.:	94	61	120
Index:	16	10	20

36. The Asani area was much like Awusiejo, in vegetation and types of water. There is little to say about climate, for the two were sprayed within a week of one another.

37. Results with Larvae

Observations on larvae were made in ten places, with the following results (given as number of larvae in 10 dips).

Ref.	Type of Place	Larvae on 31 Oct.	Larvae on 2 Nov.
A.	STILL WATERS		
4	Backwater of stream. Light overhead cover.	6	nil
6	Open swamp water lilies and much herbage. No bushes or trees, mainly *funestus*.	10	2
7	Same swamp, some overhead cover: *funestus*.	3	0
10	Open pool, shade from tall trees at edge.	10	0
B.	RUNNING STREAMS		
1	Stream under bushes.	10	10
5	Stream, heavy shade.	2	0
8	Stream, 50% cover.	7	0
9	Stream, 50% cover.	8	0
C.	CUT BAMBOOS		
2	Bamboo trough, in dense shade.	Many	Many
A	- ditto - 50% shade.	Many	Many

These results show complete kill of larvae in the majority of breeding places, but not everywhere. The failure to kill all larvae in the open swamp among such herbage (6) reminds one of the failure in both Atarаso experiments, in sedgy swamp. It seems clear that dense low vegetation (about one foot at Asani) gives a large measure of protection. Results from streams tend always to be erratic, as spray is carried to places protected by dense cover. The cut bamboos (small troughs, say one foot long and 4 in. in diameter) give complete protection as they have before. This may be due to overhead cover from tall bamboos, but it seems likely that air currents sweep the droplets past or over such an object as a cut bamboo. Survival of larvae in half coconut shells, lying on the ground has also been observed at Busua, and may be due to the same cause.

38. Results with Adults

We did not put down sheets in the catching stations during the air spray, previous work having convinced us that spray does not enter houses in sufficient quantity to kill mosquitos at rest. No cages of *Aedes* adults were exposed.

The following figures give the number of mosquitos recovered from catching stations. The two controls, Dagartikrom and Buakrom, are close together, about a mile upwind of Asani village. In all three villages the great bulk of mosquitos, about 90%, were *A. funestus*.

Asani		Before Spraying				After
	Date:	Oct. 4	19	24	28	Nov. 2
	Total Mosq.:	251	246	107	190	110
	Room Index:	63	41	18	32	18

Dagartikrom				
	Date:	Oct. 24	Oct. 28	Nov. 2
	Total Mosq.:	202	74	175
	Room Index:	50	18	44

Buakrom				
	Date;	Oct. 25	Oct. 28	Nov. 2
	Total Mosq.:	417	55	72
	Room Index:	104	14	18

It is to be noted that the populations in all three villages are fluctuating very greatly over intervals of a few days. That being so the only conclusion we can draw from these figures is that the spray certainly did not destroy large numbers of Anopheles, and that it is not proved that it killed any.

The work at Asani was very competently carried out by Staff Sergeant R. A. Davis, R.A.M.C.

SUMMARY OF COMPARISON OF DOSES IN DITCHES

39. We desired to obtain an accurate assessment of the value of our oil solution and emulsion, under conditions permitting of precise measurement. It was clear that this could not be done from the air; in view of local circumstances it seemed best to work on a system of irrigation ditches, containing larvae of A.funestus, measuring areas and putting down precise quantities of insecticide by pipette. Larvae were always counted for several days before, and many days after the insecticide had been applied. We were not trying to control larvae, but to define the point at which each material showed signs of becoming ineffective.

40. Using dieseline which contained 5% pure para para DDT (W/V), and 0.25% commercial oleic acid, it was found that a dose of 0.10 cc./sq. yard killed all larvae, and continued effective for some 4 days or so. So low a dose as 0.01 cc. killed 90 to 100% but had no lasting effect. A dose of 0.50 cc. killed all larvae, and continued to be fully effective for some 5 days; after that some larvae appeared and grew up, but the number which did so remained far below the control for as much as four weeks. This curious result, which was observed several times is most difficult to explain.

41. AMSO, which contained the same proportion of DDT seemed less effective than the dieseline solution, though the difference was not great. At 0.10 cc./sq. yard it was about equal to the dieseline. At very low doses, 0.02 cc. it failed to kill, while the dieseline killed a very high proportion at 0.01 cc. At higher doses (0.50 cc.) a similar prolonged though imperfect control was observed.

42. It must be emphasised that these doses are not recommended in practice. They tend to define the lowest effective dose when the material is put down with great care and as evenly as possible over a small area. 0.10 cc. of 5% DDT/sq. yard is equivalent to 24 gm. or 0.8 oz./acre.

APPENDIX D

Composition, Preparation and Properties of DDT Air-Spray mixtures used in W. Africa trials

by B. A. Toms

1. In the light of existing knowledge, it was deemed essential that, for experimental purposes, a DDT air-spray should have the following qualities:-

(i) The drop-density established in the target area should be the maximum possible consistent with reasonable economy of air-effort and expenditure of spray material.

(ii) When spray falls upon the surface of water, the DDT should be retained for as long as possible at the surface (where it is known to be accessible to larvae) so that larvicidal action might be achieved, by the cumulative effect of repeated small doses, in lightly contaminated breeding places.

2. In an attempt to meet these requirements, it was decided

(i) To employ spray mixtures which were easily shattered by aero-dynamic forces and of which a large proportion was dispersed as drops of the smallest sizes compatible with aimability under operational conditions of air-spraying with existing service equipment. That is, the break-up of at least half of the liquid into drops between 0.2 and 0.4 mm. diameter was desired, while much of the remainder should be dispersed as a drifting mist of small drops (less than 0.2 mm. diameter).

(ii) To incorporate lubricating oil of low volatility in the spray liquor in sufficient proportion to ensure that the whole of the DDT would be retained in solution (forming a surface film when desposited on water) when the other components of the mixture had been removed, e.g. by evaporation or solution. In this connection it was known that at 25°C. an oil solution containing approximately 7% pure DDT by weight was under-saturated, i.e. about 1.5 Imperial gallons of a lubricating oil such as Pool Grade No.3 or M.220 (H.D.50) will dissolve 1 lb. pure DDT at that temperature.

(iii) To add a spreading agent to the spray mixture with a view to increasing the coverage of natural water surfaces by impinging drops of spray. The spreading of drops of fallen spray on the surface of water is discussed in Appendix I.

The DDT Spray mixtures used

3. As indicated in 4(ii) the basic component of all the spray mixtures used in W. Africa was a lubricating oil solution containing approximately 7% pure DDT by weight. For spraying purposes this material was diluted and "thinned" in two ways:-

(i) By the addition of light oils, e.g. gas oil, kerosene, naphtha.

(ii) By the addition of water and emulsifying agent.

The material ultimately sprayed from the air was, therefore, either (a) a solution of DDT in a mixture of oils, or (b) a dilute oil-in-water emulsion with DDT dissolved in the internal phase.

Oil Spray Mixtures

4. These were made by dilution, with lubricating oil and gas oil, of a DDT/Naphtha concentrate manufactured in England (see para.14). The average composition of this concentrate was as follows:-

Component	Percentage by weight in concentrate
Pure DDT (pp'-isomer)	12.5
Impurities from Technical DDT (pp'-content = 56%)	9.7
Oleic acid (spread-aider)	2.0
Naphtha (S.G. = 0.835)	75.8

The specific gravity of the DDT/Naphtha concentrate was 0.92 and it was, therefore, calculated that one Imperial gallon of the material contained about 1.15 lb. pure DDT.

5. Naturally, the final composition of an oil spray mixture derived from the DDT/Naphtha concentrate depended upon a decision as to the total amounts of spray liquor and pure DDT to be deposited upon a selected target area. In all, two oil spray mixtures were used in the W. African trials. The ground contamination produced by each of these when dispersed as air spray under standard conditions is described in Appendix E.

DDT/Oil Mixture No.1 (Pure DDT content = 0.6% by weight)

Note. This spray mixture was used in the trials at Busua and Ataraso areas.

6. 1000 Imperial gallons of DDT/Oil mixture No.1 were made by mixing together (see para.13).

(i) 45 gallons DDT/Naphtha concentrate

(ii) 75 gallons lubricating oil M.220 (H.D.50)

(iii) 875 gallons Gas Oil (S.G. = 0.85).

(iv) 5 gallons commercial Oleic Acid

(v) 80 lbs. Williams Spirit Red III Dye (for assessment purposes).

7. In detail, the composition of the finished charging was as follows:-

Component	Percentage by weight in DDT/Oil Mixture No.1
Pure DDT (pp'-isomer)	0.6
Impurities from Technical DDT	0.45
Oleic acid	0.6
Lubricating oil	7.7
Gas oil	86.2
Naphtha	3.6
Red Dye	0.9

Notes

(i) 1000 Imperial gallons of DDT/Oil Mixture No.1 contained 52 lbs. pure DDT.

(ii) The mixture contained 1.5 Imperial gallons of lubricating oil per 1 lb. pure DDT (cf. para.4(ii)).

DDT/Oil Mixture No.2. (Pure DDT content = 2.9% by weight)

Note: This spray mixture was used in the trials at Natiem and Ntangufo.

8. 1000 Imperial gallons of DDT/Oil Mixture No.2 were made by mixing together (see para.13).

(i) 220 gallons DDT/Naphtha concentrate.

(ii) 380 gallons Lubricating Oil M.220 (H.D.50).

(iii) 400 gallons Gas Oil (S.G. = 0.85).

(iv) 80 lb. Williams Spirit Red III Dye (for assessment purposes).

9. In detail, the composition of the finished charging was as follows:-

Component	Percentage by weight in DDT/Oil Mixture No.2
Pure DDT (pp'-isomer)	2.9
Impurities from Technical DDT	2.2
Oleic Acid	0.45
Lubricating Oil	38.0
Gas Oil	38.3
Naphtha	17.3
Red Dye	0.9

Notes

(i) 1000 Imperial gallons of DDT/Oil Mixture No.2 contained 253 lb. pure DDT.

(ii) The mixture contained 1.5 Imperial gallons of lubricating oil per 1 lb. pure DDT (cf. para.4(ii)).

Physical properties of DDT/Oil spray mixtures

10. Samples of each of the several lots of DDT/Oil Mixtures Nos.1 and 2 made under W. African field conditions (see para.13) were examined in the laboratory and were found to have the following physical properties:-

DDT/Oil Mixture	Appearance	Specific gravity	Viscosity at 25°C. (centi-poises)	Spreading pressure (dynes/cm)
No.1	Homogeneous solution	0.86	3.8-3.9	28-30
No.2	Homogeneous solution	0.88	7.4-7.9	28

Preparation of DDT/Oil spray mixtures in the field

11. The DDT/Oil spray mixtures were made in 25-gallon batches each of which was stirred by hand (using a broomstick) until homogeneous. The material was then transferred to a M.10 spray tank by means of a hand-operated semi-rotary pump, two of which were in continuous use. Experience showed that a party of four Europeans and three Africans, working under supervision, could prepare 1000 gallons of either of the spray mixtures and charge the material into 40 x M.10 tanks in 2 hrs. 30 mins. by this method. Solution of the dye too, took place rapidly as the temperature of the liquid in the mixing drums was usually between 31° and 35°C.

Effect of Storage on DDT/Naphtha concentrate

12. A stock of 1000 gallons of undyed DDT/Naphtha concentrate (see para.6) was manufactured in England in April, 1944, and charged into 5-gallon drums fitted with liquid-tight screw caps. The drums were tin-plated on the inside and painted black on the outside. A specification of the contents was stencilled on each drum. The material, which was examined by Ch.I.D. before despatch, reached W. Africa in August and was stored out-of-doors, the drums being fully exposed to the weather. Concerning the condition of the material on arrival at Takoradi it was observed that

(i) All drums were rusted on the outside as a result of shipment as deck cargo. The stencilling was almost illegible.

(ii) None of the drums had leaked, and all Ch.I.D. seals were intact. The screw-caps could be removed without difficulty. A few drums, which had been overfilled, had bulged slightly through expansion of the contents.

(iii) The interiors of several drums were examined and in all cases the tinplate was found to be uniformly clean and bright.

(iv) The DDT/Naphtha concentrate was in good condition and underwent no deterioration during storage (August-November) under W. African climatic conditions. At no time can the temperature of the liquid have fallen below about 24°C. and during the day-time it was usually between 31° and 35°C.

Oil-in-Water Emulsion Spray Mixtures

13. These were made by mixing together AMSO (Anti-Mosquito Soluble Oil) and water in appropriate proportions. The water was drawn directly from the main supply at Takoradi Airport.

14. AMSO is a self-emulsifying oil manufactured in England (see para.26) by dissolving 1.5 lb. pure DDT, or the equivalent amount of Technical DDT of known pp'-content, in a mixture of

(i) 2 Imperial gallons Lubricating Oil, Pool, Grade 3 (a light machine oil of low volatility),

and (ii) 1 gallon "Amoa A.5.X.", a commercial oil-soluble emulsifier consisting of sodium oleate and turkey red oil peptised with cresylic acid and water.

In detail, the composition of the AMSO used in the W. Africa trials was as follows:-

Component	Percentage by weight in AMSO
Pure DDT (pp'isomer)	5.0
Impurities from Technical DDT (pp'-content = 80%)	1.3
Lubricating Oil (S.G. = 0.92)	60.3
Emulsifying agent	33.4

The specific gravity of AMSO was 0.95 and it was, therefore, assumed that 1 Imperial gallon of the material contained about 0.475 lb. pure DDT.

15. Naturally, the final composition of an oil-in-water emulsion spray mixture derived from AMSO depended upon a decision as to the total amounts of spray liquor and pure DDT to be deposited upon a selected target area. In all, two emulsion spray mixtures were used in the W. African trials.

DDT Emulsion No.1 (Pure DDT content = 0.5% by weight)

Note: This spray mixture was used in the trials at Awusieja and Asani areas.

16. 1000 Imperial gallons of DDT Emulsion No.1 were made by mixing together

(i) 100 gallons AMSO.

(ii) 900 gallons water.

17. In detail, the composition of the finished charging was as follows:-

Component	Percentage by weight in DDT Emulsion No.1
Pure DDT (pp'isomer)	0.5
Impurities from Technical DDT	0.1
Lubricating Oil	5.8
Emulsifying Agent	3.2
Water	90.4

Notes

(i) 1000 Imperial gallons of DDT Emulsion No.1 contained 47.5 lb. pure DDT.

(ii) The emulsion contained 1.3 Imperial gallons of lubricating oil per 1 lb. pure DDT (cf. para.4(ii)).

DDT Emulsion No.2 (Pure DDT content = 1.0% by weight)

Note: This spray mixture was used in the first trial at Ataraso area.

18. 500 Imperial gallons of DDT emulsion No.2 were made by mixing together

(i) 100 gallons AMSO.

(ii) 400 gallons Water.

19. In detail, the composition of the finished charging was as follows:-

Component	Percentage by weight in DDT Emulsion No.2
Pure DDT (pp'isomer)	1.0
Impurities from Technical DDT	0.2
Lubricating oil	11.6
Emulsifying agent	6.4
Water	80.8

Notes

(i) 500 Imperial gallons of DDT Emulsion No.1 contained 47.5 lb. pure DDT.

(ii) The emulsion contained 1.3 Imperial gallons of Lubricating oil per 1 lb. pure DDT (cf. para.4(ii)).

Physical Properties of DDT Emulsion Spray Mixtures

20. Samples of each of the several lots of DDT Emulsions Nos.1 and 2 made under W. African field conditions (see para.24 and 27) were examined in the laboratory and were found to have the following physical properties:-

DDT Emulsion	Volume percentage of internal (oil) phase	Specific gravity	Viscosity at 25°C. (centipoises)	Spreading pressure (dynes/cm.)
No.1	10	ca. 1.0	1.1	46
No.2	20	ca. 1.0	1.4	46

Preparation of DDT Emulsion spray mixtures in the field

21. The preparation of small amounts of AMSO emulsions presented no difficulty; to the requisite amount of AMSO was added an approximately equal volume of cold water and then the liquids were thoroughly mixed together by vigorous stirring or shaking. The concentrated oil-in-water emulsion so formed could then be diluted with water to any desired extent. Dilute emulsions made in this way were remarkably stable and did not "cream" when stored for as long as six weeks under W. African climatic conditions. When, however, this simple method was used in the field for the large-scale manufacture of dilute emulsions (25 gallons batches were mixed by stirring with broomsticks) certain difficulties were encountered. Although the emulsions showed no signs of breakdown, i.e. separation of free oil at the surface, after storage for several days, the globules of internal phase rapidly became segregated at the surface of the system. While it was considered that such emulsions would almost certainly be rendered uniform again by the agitation received when aircraft take-off on a spraying mission, efforts were made to reduce the rate of creaming as much as possible by altering the method of manufacture so as to produce a finer dispersion of the oil phase.

(Note: Comparison, under the microscope, of specimens of dilute AMSO emulsions made in the laboratory and in the field, showed that the former contained fewer large globules, 5-10 microns in diameter, than the latter). To this end, a process of homogenisation was devised and introduced. A substantial reduction of both the rate and the extent of "creaming" was thereby achieved (see para.27).

22. The method of making large quantities of dilute emulsions finally adopted can be illustrated by reference to the preparation of a 25 gallon (= liquid capacity of 1 x M.10 tank) batch of DDT Emulsion No.1:-

(i) New and absolutely clean mixing drums were obtained. All M.10 tanks which had previously been filled with a dyed oil mixture were washed out twice with kerosene and then with water.

(Note: It had been found that small traces of either the oil-soluble Williams Spirit Red III Dye or the water-soluble Acid Scarlet Dye supplied for characterising the spray mixtures rendered AMSO emulsions unstable under W. African field conditions.)

(ii) 2.5 gallons of AMSO were placed in a small "pre-mixing" drum of 8 gallons capacity and stirred vigorously by hand while 3-4 gallons of water were added slowly.

(iii) The concentrated oil-in-water emulsion so formed was then transferred to a large mixing drum by means of a Stirrup Pump (Standard M.O.H.S. pattern, fitted with $\frac{1}{8}$-in. jet nozzle, and operated by hand). Three stirrup pumps were used simultaneously and the transfer could be completed in a few minutes. The residual liquor in the pre-mixing drum was then mixed with 1-2 gallons of water and the pumping repeated. Finally, the dregs of emulsion in the pre-mixing drum were poured into the large vessel to ensure that the latter contained exactly 2.5 gallons of emulsified AMSO.

(iv) Water was then added to the large drum until the total volume of the dilute emulsion was 25 Imperial gallons. The finished emulsion, after thorough stirring, was transferred to a M.10 tank by means of a hand-operated semi-rotary pump.

23. On two occasions a party of four Europeans and three Africans, working under supervision, made 1000 Imperial gallons of DDT Emulsion No.1 and charged the material into 40 x M.10 tanks in 3-3½ hours by this method. The manufacturing process, which proved quite suitable for field use, may be summarised thus:-

AMSO ⟶ Pre-mixing drum (hand-stirring) ⟵ Water
↓
Stirrup Pump (homogenisation)
↓
Large mixing drum (hand-stirring) ⟵ Water
↓
M.10 Tank.

Effect of Storage on AMSO

24. A stock of ca. 350 gallons of AMSO (see para.16) was manufactured in England in May 1944, and charged into 5 gallon drums fitted with liquid-tight screw caps. The drums were tin-plated on the inside and painted yellow on the outside. A specification of the contents was stencilled on each drum. The material, which was examined by Ch.I.D. before despatch, reached W. Africa in August and was stored out-of-doors, the drums being fully exposed to the weather. Concerning the condition of the material on arrival at Takoradi it was observed that

(i) No drum had become rusted as a result of shipment as deck cargo. The paintwork was intact and the stencilling legible.

(ii) Only one drum had leaked, and all Ch.I.D. seals were intact. The screw caps could be removed without difficulty.

(iii) The interiors of several drums were examined and in all cases the tin-plate was found to be uniformly clean and bright.

(iv) The AMSO complied with Porton Specification and underwent no deterioration during storage (August - November) under W. African climatic conditions. At no time can the temperature of the liquid have fallen below about 24°C. and during the daytime it was usually between 31° and 35°C.

Effect of Storage on dilute emulsions of AMSO

25. Tests indicate that samples of DDT Emulsion Nos.1 and 2 prepared in the laboratory could be stored in glass or tin-plate vessels for long periods under W. African climatic conditions without deteriorating. Thus, after six weeks storage in a glass cylinder, no free oil had separated from a specimen of Emulsion No.1, nor had creaming occurred. Specimens of DDT Emulsions Nos.1 and 2 manufactured in the field (see para.24) exhibited a similar degree of stability, but some segregation of the phases (creaming) became apparent after 2-3 days though the process was arrested once the small proportion of large (5-10 microns diameter) globules had risen to the surface.

26. It was concluded, therefore, that a dilute aqueous emulsion of AMSO is stable when correctly prepared under field conditions and is a satisfactory spray charging for operational purposes in W. Africa.

Summary

27. DDT Air-spray mixtures for use in the W. African Trials were so compounded as to meet certain requirements pertaining to the killing of larval and adult mosquitos. The basic constituent of all mixtures was a 7% (approx.) solution of pure DDT in lubricating oil of low volatility. For spraying purposes this material was diluted and "thinned" by addition of either (i) light oils, e.g. gas oil, kerosene, naphtha, or (ii) water and emulsifying agent.

28. In all, four different spray mixtures were used and their salient properties were as follows:-

Spray Mixture	DDT Content (% by weight of pure DDT)	Specific gravity	Viscosity at 25 C. (centi-poises)	Spreading pressure (dynes/cm.)
DDT/Oil Mixture No.1	0.6	0.86	3.8-3.9	28-30
DDT/Oil Mixture No.2	2.9	0.88	7.4-7.9	28
DDT/Emulsion No.1	0.5	1.0	1.1	46
DDT/Emulsion No.2	1.0	1.0	1.4	46

The performance of these mixtures as air-sprays under standard conditions is described in Appendix E.

Performance of the DDT/Oil Mixtures used in the W. Africa Trials when employed as air-sprays under standard conditions

by B. A. Toms and J. W. Siddorn

Introduction

1. Each of the main trials carried out in W. Africa involved the distribution, as air-spray, of a large quantity of liquid (e.g. 1000 Imperial gallons), containing a specified amount of DDT, over an area of country which was usually one mile square. *A priori*, it was required that all parts of the target area should be contaminated as uniformly as possible with fallen spray and that the drop density should be high. Vengeance aircraft, carrying American tanks, Airplane M.10 fitted with 2½ in. emission nozzles, were the means available for accomplishing this task.

2. To meet the requirements it was decided to lay across the target area, a number of parallel 'swathes' of air-spray, each about 2,000 yards long (i.e. about 1 mile), by means of successive sorties of five aircraft flying across-wind in formation and at low altitude. It was agreed that the spacing between aircraft should be such that a substantial overlap of neighbouring swathes of spray would be achieved. In this way serious 'gaps' in the liquid contamination on the target area, caused by emission failures among the spray tanks and/or errors in flying, would be largely avoided.

3. The problem of producing an unbroken swathe of spray 2,000 yards in length was solved by arranging that each aircraft, flying at 220-230 mi/hr., discharged the second of its two spray tanks 9 seconds after the first. A decision as to the spacing between aircraft needed to produce an adequate downwind overlap of neighbouring swathes of spray was based upon information concerning the performance, as airspray, of a selected DDT/Oil mixture which, however, was not used in any of the large-scale trials on square-mile target areas. This information comprised the nature and distribution of the liquid contamination deposited upon open level ground under standard conditions of air-spraying and was obtained empirically in a small-scale trial. The purpose of the present assessment trials was to determine the relevance of these earlier findings to the air-spraying DDT/Oil Mixtures Nos. 1 and 2 (described in Appendix D), both of which differed in composition from the original spray mixture.

Description

Site and sampling method

4. Two trials were carried out, at low tide, on mud-flats situated between Takoradi Airport and the sea. The sampling layout consisted of envelopes laid downwind in two parallel rows, 300 yards apart and 600 yards long. The envelopes in each row were spaced at 10-yard intervals for the first 200 yards, at 20-yard intervals for the next 200 yards, and at 50-yard intervals thereafter. A fresh layout was prepared for each trial.

Spray materials

5. The trials concerned assessment of the performance of the DDT/Oil spray mixtures (specified in Appendix D) only, because the DDT Emulsion spray mixtures could not be characterised with the dyes available (see Appendix D).

6. 25 Imperial gallons of each of

(i) DDT/Oil Mixture No.1, containing 0.6% pure DDT by weight.

(ii) DDT/Oil Mixture No.2, containing 2.9% pure DDT by weight.

were charged into two M.10 tanks, fitted with 2½ in. reducing thimbles, which were carried on a Vengeance Mk.IV aircraft.

Spraying technique

7. The aircraft flew acrosswind at 200-220 mi/hr. at an altitude of 100 ± 10 feet discharging the spray tanks one at a time on successive runs. The line of flight, and pull-off point, were indicated by smoke signals on the ground.

Meteorological conditions

8. During both emissions, each of which lasted about 10 seconds, the wind, which was a sea-breeze, blew steadily from a south-westerly direction. On both occasions a wind-speed of 13.7 mi/hr. was recorded by cup anemometer at 6 feet above ground level, the mean wind to spraying height being about 18 mi/hr. The height-wind product (HW = feet x miles per hour) pertaining to both sprays was, therefore, approximately 1,800. The air temperature at the time of the trial was 84°F.

Results

9. In both experiments, which were completed in one hour, the whole of the air-spray, with the exception of some drifting mist, fell within the boundaries of the target area. A satisfactory sample of the ground contamination was therefore obtained on both layouts.

(A) Drop-spectra of the air-sprays

(i) Size-distribution of drops collected

Drop-Diameter (mm.)	Percentage of drops in stated size-class	
	DDT/Oil Mixture No.1	DDT/Oil Mixture No.2
Less than 0.2	63.0	66.0
0.2 to 0.4	33.7	31.0
0.4 to 0.6	3.2	2.8
0.6 to 0.8	0.1	0.17
0.8 to 1.0	0	0.03
Greater than 1.0	0	0

Note. Owing to the observed selective loss of very small drops, which were blown beyond the end of the layout, the mean drop-size must have been smaller than shown here.

(ii) Mass (volume) distribution of chargings

Drop-Diameter (mm.)	Percentage of charging dispersed in drops of stated size-range	
	DDT/Oil Mixture No.1	DDT/Oil Mixture No.2
Less than 0.2	20.0	18.0
0.2 to 0.4	60.0	62.5
0.4 to 0.6	19.4	17.7
0.6 to 0.8	0.6	1.7
0.8 to 1.0	0	0.1
Greater than 1.0	0	0

Note. The accuracy of these figures is almost unimpaired by the selective loss of small drops.

10. The data presented in para.9 show that under the experimental conditions both air-sprays had substantially the same drop-spectrum. In both cases it was found that

(i) The median drop-diameter was less than 0.17 mm. and 50% of the liquid was dispersed as drops smaller than 0.29 mm. diameter.

(ii) The diameters of the largest drops did not exceed 1.0 mm.

(iii) About 60% of the spray liquid was dispersed as drops having diameters between 0.2 and 0.4 mm.

(iv) About 20% of the spray liquid was dispersed as drops having diameters smaller than 0.2 mm.

(v) Less than 2% of the spray liquid was dispersed as drops exceeding 0.6 mm. diameter.

It will be seen, therefore, that DDT/Oil Mixtures Nos. 1 and 2 comply very closely with the requirements laid down for DDT air-spray in Appendix D, para.3(i). Moreover, their drop spectra are very similar to that mentioned in para.3 for an oil spray mixture of quite different composition.

(B) <u>Distribution of spray liquid on the ground</u>

11. The downwind distribution of liquid on open, level ground when 25 gallons of either DDT/Oil Mixture No.1 or DDT/Oil Mixture No.2 were discharged as air-spray under the conditions of the present trials may be summarized in tabular form:-

Distance (yards) measured downwind from the upwind edge of the area contaminated with fallen spray	Average density (mgm per m^2) of liquid contamination in specified "strip" of ground		Percentage by weight of total charging (100 Kg.) deposited on specified "strip" of ground	
	DDT/Oil Mixture No.1	DDT/Oil Mixture No.2	DDT/Oil Mixture No.1	DDT/Oil Mixture No.2
0 to 100	220	490	22.0	49.0
100 to 200	450	344	45.0	34.4
200 to 300	227	136	22.7	13.6
300 to 400	166	124	16.6	12.4
400 to 500	(?)	61	(?)	6.1
	Total Recovery		106.3%	115.5%

<u>Note.</u> It will be observed that the estimated total 'recovery' of charging on the target area exceeded the theoretical value, but was of the same order of magnitude, in both trials. The discrepancy may be ascribed to systematic errors, of both a practical and theoretical character, in the simple method of assessment used, and it is therefore not unreasonable to compare the performances of the two air-sprays.

12. Examination of the data presented in the preceding paragraph shows that the distributions of ground contamination in the two experiments were not grossly dissimilar and were characterised by the uniformity in contamination-density over the first 300 yards. Moreover, there was no evidence of excessive liquid contamination having been deposited on a narrow strip along the upwind edge of the target area.

<u>Conclusions</u>

13. On the evidence presented, it is concluded that the performance, as air-sprays, of DDT/Oil Mixtures Nos.1 and 2, was substantially the same as that

used in the 26th Milestone area trial mentioned in para.11 of the main report. On the basis of this latter assessment it had been decided to adopt a standard air-spraying procedure, involving a 100 yard spacing between neighbouring aircraft, with the object of ensuring an almost uniform distribution of spray liquid (and of DDT) and a high drop density over a target area one mile square. It is reasonable to suppose that a similar distribution of insecticide was achieved by spraying DDT/Oil Mixtures Nos.1 and 2 under the same conditions.

14. Concerning the deposition, on target areas one mile square, of 1,000 Imperial gallons of either of DDT/Oil Mixture Nos.1 and 2, by means of 40 x M.10 tanks carried on 20 Vengeance aircraft, under the flying conditions pertaining to the large-scale air spray trials, it can be computed that an almost uniform spray contamination must have been produced over 80-90% of the target area. In these circumstances, the order of magnitude of the DDT dosage established in the sprayed area in each trial can be found by dividing the total amount of DDT used by the nominal area of the target. The nominal dosages given in Table B, C.D.E.S. Report were computed in this way.

Summary

15. Data concerning the performance, as air-sprays delivered under standard conditions, of DDT/Oil Mixtures Nos.1 and 2 which were employed in W. African trials for effecting the distribution of DDT over one mile square areas of country (see Appendix D), have been obtained in small scale trials over open, level ground. The relevance of these findings to the spraying of large target areas in a standard manner is discussed.

16. No assessment of the performance, as air sprays, of DDT Emulsions Nos.1 and 2 (see Appendix D) could be made.

WEATHER IN THE S.W. AREA GOLD COAST WITH SPECIAL REFERENCE TO THE MONTHS SEPT., OCT., NOV.

The latitude of the region (c.4½ degs.N) gives reason to expect equatorial climate and a glance at the statistical tables will bear this out. At no time does the humidity fall below 75% and with a mid-day temperature consistently above 80 degs.F. the coastal belt of the Gold Coast is truly equatorial.

Normally in West Africa the year is divided into a wet season and a dry season but on the Gold Coast there are two wet seasons, the main wet season around May when the Doldrum Belt is migrating north across the area and the small wet season in late Oct. and early Nov. when the Doldrums are returning south with the sun.

General Statement of Climatic Elements

Wind. The first feature to notice is the dividing line, near the coast in Feb. well inland in Aug. called the Inter-tropical Front (ITF). To the north of the ITF the winds are mainly E-NE; to the south the winds are mainly SW. The E-NE winds have a long desert track and are therefore dry and warm by day, and cool by night. The SW winds are a deflected extension of the SE Trades which blow south of the Equator and may be regarded as colossal sea breezes. On account of their long sea track the SW winds bring very humid air to the coast and are almost entirely responsible for the rainfall.

Hence it may be said that in the SW Gold Coast the wind direction is predominantly SW and the surface speed rarely above 15 m.p.h. Temperature and Humidity. Temperature and humidity vary greatly in different parts of West Africa, the deciding factor being the distance away from the coast. At Kano in North Nigeria it is common in the dry season to have a night minimum of 50 degs.F. and a day maximum of over 110 degs.F. At this period Kano is completely within the dry NE'ly air stream and during the day the humidity may fall below 10%.

Turning to the tables for the Gold Coast it will be seen that the humidity is never below 75% and the daily range of temperature seldom greater than 10 degs.F. with a day minimum between 85 and 90 degs.F. The explanation is the fact that (a) The Gold Coast is permanently under the influence of the moist SW'lies and (b) the temperature of the sea off the coast has an annual variation of only 10 degs.F.

Rainfall. Rainfall is the most variable of all climatic elements and within West Africa there are some of the wettest and driest regions of the world. In 1882 Freetown experienced 202 inches of rain and yet in the Senegal Desert it is common to see no running water for 7½ months. Due partly to the shape of the coastline and partly to the slightly cooler currents in the neighbouring sea the Gold Coast does not lie within the wettest region and Takoradi has an annual rainfall of only 50 inches (approx.). The bulk of the rain falls in May and June and Takoradi has an average total of only 9 inches for the three months Sept. Oct. and Nov. It will be seen that Axim has twice as much rainfall during the year and also during the three months under consideration at Takoradi. An explanation of this difference is given below.

Local Effects. A trip by road from Takoradi to Axim quickly demonstrates the change in climatic conditions over a relatively short distance. Not only does the sky become more overcast and the showers more frequent but the change is revealed in the vegetation. At Takoradi the bush is fairly sparse and more of the savanna type whereas near Axim the forests are typically equatorial. The explanation lies in the fact that the prevailing SW'lies strike the Axim coast almost at right angles giving the maximum orographic effect whereas the coast East of Cape Three Points is almost parallel to the wind flow.

Actual Weather experienced during Operations. The experiments were carried out as a rule between 0900 and 1500 hours. The normal sequence of weather was as follows: Fair conditions would be left behind at Takoradi and the cloud would increase and lower steadily westwards. During the operations the cloud was generally about 7/10 at 1000-2000 feet with occasional light showers. The air temperature was usually between 80-85 F. (27-29°C.) and the humidity about 80%. The persistent SW'ly simplified the setting up of lines of flight and the speed (always between 5-15 m.p.h.) was ideal for spraying purposes.

(Sgd.) J. Spurr.

F/Lt.
SENIOR MET. OFFICER.
TAKORADI

AVERAGE VALUES OF SURFACE WIND DIRECTION AND SPEED (M.P.H.) - S.W. AREA, GOLD COAST. (AT SPECIFIED HOURS G.M.T.)

SEPTEMBER	0800	1000	1300	1600
AXIM	-	SW'ly 6-10 m.p.h.	SSW'ly 10-14 m.p.h.	SW'ly 10-14 m.p.h.
TAKORADI	WSW'ly 4-7 m.p.h.	SW 6-10 m.p.h.	SSW 12 m.p.h.	SW 8-12 m.p.h.
TARKWA	Calm	SW'ly 5-10 m.p.h.	SW'ly 8-12 m.p.h.	SW'ly 8-12 m.p.h.
OCTOBER				
AXIM	-	SW'ly 6-10 m.p.h.	SSW'ly 10-14 m.p.h.	SW'ly 10-14 m.p.h.
TAKORADI	W'ly 2-4 m.p.h.	SW'ly 6-10 m.p.h.	SSW 12 m.p.h.	SW'ly 8-12 m.p.h.
TARKWA	Calm	SW'ly 5-10 m.p.h.	SW'ly 8-12 m.p.h.	SW'ly 8-12 m.p.h.
NOVEMBER				
AXIM	-	SW'ly 6-10 m.p.h.	SSW'ly 10-14 m.p.h.	SW'ly 10-14 m.p.h.
TAKORADI	W'ly 2-4 m.p.h.	SW'ly 4-7 m.p.h.	SW 11 m.p.h.	SW 6-10 m.p.h.
TARKWA	Calm	SW'ly 5-10 m.p.h.	SW'ly 6-10 m.p.h.	SW'ly 6-10 m.p.h.

F/Lt.
Senior Met. Officer, Takoradi.

SEPTEMBER CLIMATOLOGICAL AVERAGES - S.W. AREA, GOLD COAST

				TEMPERATURE						HUMIDITY			RAINFALL					
Lat.	Long	Ht.	Station	Dry Bulb at 0700	Dry Bulb at 1400	Max.	Min.	Mean	Solar Max.	At 0700	At 0900	At 1400	Total in month		Max. in 24 hours			No. of Wet days
N.	W.	Feet		°F	°F	°F	°F	°F	°F	%	%	%	ins.	mms.	ins.	mms.	Date	
4.56	2.21	-	ESIAMA	-	-	85	72	79	(A) 138.5	-	84	-	4.16	105.7	3.05	77.5	30th (1940)	10
4.52	2.14	75	AXIM	74.0	80.4	82	73	77	(A) 140.7	92	86	81	2.14	54.4	1.88	47.8	28th (1940)	11
4.53	1.46	15	TAKORADI	72.7	79.0	81	71	76	(A) 134.5	95	81	80	1.85	47.0	1.52	38.6	18th (1941)	15

N.B. Takoradi temperature averages derived from period: 1939 - 43. For Cloud and Surface Wind data, see Separate Sheet.

(Sgd.) J. Spurr.
F/Lt.,
SENIOR MET. OFFICER,
TAKORADI

OCTOBER CLIMATOLOGICAL AVERAGES - S.W. AREA, GOLD COAST

Lat.	Long	Ht.	Station	TEMPERATURE						HUMIDITY			RAINFALL					No. of Wet days
				Dry Bulb at 0700	Dry Bulb at 1400	Max.	Min.	Mean	Solar Max.	At 0700	At 0900	At 1400	Total in Month		Max. in 24 hours			
N.	W.	Ft.		°F	°F	°F	°F	°F	°F	%	%	%	ins.	mms.	ins.	mms.	Date	
4.56	2.21	-	ESIAMA	-	-	87	73	80	144.6	-	83	-	10.06	255.5	4.12	104.6	19th (1942)	16
4.52	2.14	75	AXIM	74.9	81.3	83	73	78	141.9	93	83	81	9.23	234.4	6.02	152.9	3rd (1935)	15
4.53	1.46	15	TAKORADI	73.6	81.8	83	72	77	139.5	96	77	77	4.25	108.0	3.54	89.9	24th (1937)	14

Notes: Takoradi Temperature averages derived from period: 1939 - 43.

(Sgd.) J. Spurr.
F/Lt.

SENIOR MET. OFFICER.
TAKORADI

NOVEMBER CLIMATOLOGICAL AVERAGES - S.W. AREA, GOLD COAST

Station	TEMPERATURE						HUMIDITY			RAINFALL					No. of Wet days
	Dry Bulb at 0700	Dry Bulb at 1400	Max.	Min.	Mean	Solar Max.	At 0700	At 0900	At 1400	Total in Month		Max. in 24 hours			
	°F	°F	°F	°F	°F	°F	%	%	%	ins.	mms.	ins.	mms.	Date	
ESIAMA	-	-	89	72	81	146.4	-	81	-	8.65	219.7	3.50	88.9	17th (1936)	12
AXIM	74.4	85.3	87	73	80	141.4	94	79	75	7.59	192.8	4.02	102.1	4th (1935)	13
TAKORADI	73.5	84.2	85	72	79	137.7	95	75	74	2.80	71.1	3.27	83.1	23rd (1938)	9

N.B. Takoradi temperature averages derived from period: 1939 - 43.

(Sgd.) J. Spurr.
F/Lt.

Senior Met. Officer,
TAKORADI

AVERAGE CLOUD CONDITIONS - S.W. AREA, GOLD COAST: MET. OFFICE, TAKORADI

STATION	0700				1000				1300				1600				1800			
	Low Cloud		Ht. Ft.	Total Cloud Amt.	Low Cloud		Ht. Ft.	Total Cloud Amt.	Low Cloud		Ht. Ft.	Total Cloud Amt.	Low Cloud		Ht. Ft.	Total Cloud Amt.	Low Cloud		Ht. Ft.	Total Cloud Amt.
	Form	Amt.			Form	Amt.			Form	Amt.			Form	Amt.			Form	Amt.		
SEPTEMBER																				
AXIM	Layer of Sc.	5/10	800 to 1000	8/10	Layer of Sc.	5/10	1000	9/10	Large Cu. & Sc.	5/10	2000	8/10	Large Cu. & Sc.	7/10	2500	8/10	-	-	-	-
TAKORADI	Large Cu. & Sc.	6/10	1500	9/10	-	-	-	-	Large Cu.	4/10	2500	7/10	-	-	-	-	Large Cu.	4/10	2500	7/10
TARKWA	Layer of Sc.	6/10	800 to 1000	8/10	Layer of Sc.	7/10	800 to 1000	9/10	Large Cu.	7/10	2000	9/10	Large Cu. & Sc.	7/10	2500	8/10	-	-	-	-
OCTOBER																				
AXIM	Layer of Sc.	5/10	800 to 1000	8/10	Large Cu.	5/10	1500	8/10	Large Cu.	4-5/10	2000	8/10	Large Cu. & Sc.	5/10	2500	8/10	-	-	-	-
TAKORADI	Large Cu. & Sc.	4/10	1500	6/10	-	-	-	-	Cb. or Large Cu.	4/10	2500	6/10	-	-	-	-	Cb. or Large Cu. & Sc.	4/10	2500	7/10
TARKWA	Layer of Sc.	5/10	800 to 1000	9/10	Large Cu. & Sc.	6/10	1500	9/10	Large Cu.	6/10	2000	8/10	Sc.	7/10	2500	8/10	-	-	-	-

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STATION	0700				1000				1300				1600				1800			
	Low Cloud		Ht. Ft.	Total Cloud Amt.	Low Cloud		Ht. Ft.	Total Cloud Amt.	Low Cloud		Ht. Ft.	Total Cloud Amt.	Low Cloud		Ht. Ft.	Total Cloud Amt.	Low Cloud		Ht. Ft.	Total Cloud Amt.
	Form	Amt.			Form	Amt.			Form	Amt.			Form	Amt.			Form	Amt.		
NOVEMBER																				
AXIM	Large Cu. & Sc.	3/10	1000	6/10	Large Cu. & Sc.	3/10	2000	6/10	Cb. or Large Cu.	2/10	2500	6/10	Cb. or Large Cu. & Sc.	5/10	2000	7/10	Cb. or Large Cu. & Sc.	5/10	2000	8/10
TAKORADI	Large Cu.	3/10	2000	6/10	-	-	-	-	Cb. or Large Cu.	4/10	2500	5/10	-	-	-	-	Large Cu. & Sc.	4/10	2000	6/10
TARKWA	Layer of Sc.	6/10	800 to 1000	8/10	Large Cu. & Sc.	6/10	800 to 1000	7/10	Cb. or Large Cu.	6/10	2500	7/10	Cb. or Large Cu. & Sc.	6/10	2000	8/10	-	-	-	-

RAINFALL FOR AXIM AND TAKORADI. AUGUST TO NOVEMBER, 1944

DATE	AUGUST				SEPTEMBER				OCTOBER				NOVEMBER			
	AXIM		TAKORADI		AXIM		TAKORADI		AXIM		TAKORADI		AXIM		TAKORADI	
	MM	INS	MM	INS	MM	INS	MM	INS	MM	INS	MM	INS	MM	INS	MM	INS
1					Nil	Nil	Tr.	Tr.	0.7	0.03	0.5	0.02	Nil	Nil	Tr.	Tr.
2					Nil	Nil	Tr.	Tr.	2.1	0.08	1.4	0.06	0.5	0.02	Tr.	Tr.
3					Tr.	Tr.	Nil	Nil	-	-	Tr.	Tr.	Nil	Nil	Nil	Nil
4					Tr.	Tr.	2.6	0.10	0.1	0.00	Tr.	Tr.	Nil	Nil	Nil	Nil
5					1.1	0.04	1.8	0.07	0.1	0.00	-	-	1.2	0.05	9.8	0.39
6					13.5	0.53	2.7	0.11	-	-	-	-	4.1	0.16	0.2	0.01
7					7.1	0.28	Tr.	Tr.	-	-	-	-	Nil	Nil	Nil	Nil
8					2.9	0.11	0.1	0.0	3.4	0.13	-	-	0.3	0.01	Nil	Nil
9					0.5	0.02	4.2	0.17	-	-	-	-	0.3	0.01	Nil	Nil
10					3.4	0.13	0.1	0.0	Tr.	Tr.	0.3	0.01	10.7	0.42	Nil	Nil
11					0.6	0.02	Nil	Nil	Tr.	Tr.	0.2	0.01	Nil	Nil	Tr.	Tr.
12					Tr.	Tr.	Nil	Nil	0.1	0.00	Tr.	Tr.	Nil	Nil	Nil	Nil
13					Nil	Nil	0.2	0.01	30.0	1.18	24.6	0.97	Nil	Nil	Nil	Nil
14					Tr.	Tr.	Tr.	Tr.	0.3	0.01	2.8	0.11	Nil	Nil	0.3	0.01
15	0.3	0.01	Tr.	Tr.	0.8	0.03	Tr.	Tr.	0.5	0.02	-	-				
16	Nil	Nil	Nil	Nil	1.5	0.06	Nil	Nil	-	-	-	-				

DATE	AUGUST				SEPTEMBER				OCTOBER				NOVEMBER			
	AXIM		TAKORADI		AXIM		TAKORADI		AXIM		TAKORADI		AXIM		TAKORADI	
	MM	INS	MM	INS	MM	INS	MM	INS	MM	INS	MM	INS	MM	INS	MM	INS
17	Nil	Nil	0.3	0.01	Nil	Nil	0.4	0.02	-	-	-	-				
18	2.0	0.08	1.7	0.07	Nil	Nil	1.2	0.05	0.3	0.1	-	-				
19	0.3	0.01	0.3	0.01	0.9	0.03	0.9	0.04	0.3	0.1	-	-				
20	Nil	Nil	Tr.	Tr.	2.0	0.08	2.7	0.11	10.0	0.39	Tr.	Tr.				
21	Nil	Nil	Nil	Nil	2.8	0.11	0.7	0.03	0.4	0.02	-	-				
22	Nil	Nil	Nil	Nil	0.3	0.01	Nil	Nil	3.1	0.12	0.1	0.00				
23	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	24.2	0.59	15.3	0.60				
24	Tr.	Tr.	Tr.	Tr.	Nil	Nil	0.1	0.0	-	-	-	-				
25	Nil	Nil	Tr.	Tr.	7.7	0.30	1.1	0.04	4.2	0.17	4.3	0.17				
26	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	1.0	0.04	Tr.	Tr.				
27	0.3	0.01	Tr.	Tr.	Nil	Nil	Nil	Nil	4.1	0.16	-	-				
28	Nil	Nil	0.5	0.02	0.5	0.02	Nil	Nil	1.3	0.04	Tr.	Tr.				
29	2.5	0.11	3.5	0.14	15.3	0.60	0.9	0.04	-	-	-	-				
30	Nil	Nil	Tr.	Tr.	Tr.	Tr.	Nil	Nil	27.8	1.09	0.5	0.02				
31	Nil	Nil	0.2	0.01					15.6		18.3	0.79				
TOTAL	5.4	0.22	6.5	0.26	61.9	2.44	19.7	0.79	129.6	5.11	68.3	2.69	17.1	0.67	10.3	0.11

ORGANISATION AT BASE

by A. J. Black, W/Comdr.

1. Site

The site allocated to Porton Experimental Unit as a base for operations was a fortunate choice as it was situated adjacent to the main runway at Takoradi, and had a surround of wide tarmac strip which proved ideal for dispersal, aircraft maintenance, bombing up and refuelling operations.

On the site was a block of offices consisting of seven rooms; these were used to house administrative staff, aircrews and to store items of valuable equipment. A large hangar capable of holding 4 Vengeance aircraft was also available. Small dumps of oil, kerosene, DDT concentrate (in 5 gallon drums) were created on the site and each dump was suitably marked for identification purposes. Crated and uncrated S.C.I. together with all handling equipment were located near the centre of the site where an aeroplane case was erected to house such equipment as was required for the preparation of chargings and S.C.I. Good road access to the site and the aircraft dispersal points made movement of materials and personnel a simple matter. The general set up at the base proved very satisfactory and this was largely due to the compact arrangement of dumps and equipment and their close proximity to the mixing and charging plant, which obviated handling and movement of stores over long distances.

2. Transport

M/T vehicles were allocated for the sole use of the unit and were driven by personnel of the unit who were first road tested by competent M/T staff before being authorised to drive.

This arrangement worked extremely well. All vehicles were serviced daily and each driver vetted his vehicle before taking it on the road. A log book showing mileage, fuel used, and repairs was kept for each vehicle, entries being made daily.

The vehicles allocated were:-

3 Ton — Covered lorry - for conveying ground and air crews to and from their quarters and the site. Men's quarters were 5-6 miles from the site. Also for movement of stores items.

30 cwt. — Box Wagon - for conveying officers (15) to and from their quarters and the site and for use on the airfield.

Desert Car — For conveying field equipment and members of the field team to the site of the trial. This vehicle had selective four wheel drive and could traverse practically any kind of road or track. It was also useful for towing purposes and for dragging vehicles out of ditches, etc.

Jeep — The small wheel base and track, coupled with selective four wheel drive, enabled members of the field team to reach parts of the trials area which were inaccessible to other types of vehicle.

Humber Car — This vehicle was equipped with V.H.F. and Bendix radio equipment for communication between aircraft and the field team during trials.

Motor Cycle — For D.R. work.

Ambulance — The type of country and the low height at which air spraying was done, also the distance of the trials area from base (sometimes 40-50 miles), made it necessary to include a fully equipped ambulance in the team of field vehicles. The ambulance was not a permanent allocation, but was provided on request.

Other items included a Tractor, 900 gall. Bowser and a bomb trolley.

3. Personnel

The unit consisted of the following personnel:-

W/Comdr. Black (Porton)	Officer Commanding
S/Ldr. Phillips Dr. Toms Mr. Siddorn Mr. Fryer E.S.M. Goldthorpe, R.A. Sgt. Jackson, R.A.F.	Porton Field Team
Professor Buxton, F.R.S.	London School of Tropical Medicine
F/Lt. Hedley (110 (H) Sqdn.)	Flight Commander
7 Officers (110 (H) Sqdn.) 8 Warrant Officers (110 (H) Sqdn.)	Air Crew
22 N.C.Os. (9 Air crew 110 (H) Sqdn.)	
40 Airmen	
12 Natives (W.A.A.F.)	
Total 96	

4. Preparation of S.C.I. and chargings

Two types of S.C.I. were available at Takoradi, e.g. Standard 500 lb. British S.C.I. type S/G and the American tank, airplane M.10. There being no difference in the performance of the two types, the M.10 tank was selected because of its lightness which facilitated handling and bombing up operations and its general availability in most operational areas. A carrier adapter and fairing was fitted to the M.10 tank to enable it to be carried on British Universal Mk.III carriers. A reducing thimble was fitted over the standard 5" dia. outlet to restrict the emission outlet to 2½". Early tests showed a weakness in the method of attaching this item to the 5" nozzle, but this was overcome by using thicker gauge metal for the retaining straps and replacing rivets by bolts.

Preliminary air trials indicated that the air inlet disc could be dispensed with as there was no significant spillage at this point when the disc was omitted. Standard procedure was followed in the fitting of the emission Bakelite disc and detonator.

Chargings were made up in twelve 45 gall. oil drums with tops removed, and mixed by hand using broom handles. The charging was then transferred to S.C.I. by means of two hand operated semi-rotary pumps. This method was found to be quick and efficient and very little loss occurred during the process.

When possible, S.C.Is. were charged and detonators fitted to the emission discs the afternoon before a trial. Serviceable aircraft were bombed up the same afternoon, but S.C.I. leads were left disconnected. On the morning of the trial all final connection were made, S.C.I. and bombing circuits tested and vetted by aircraft and armament N.C.Os.

The average time taken to mix the charging, prepare, charge, and 'det-up' 40 S.C.I., ready for bombing up, was 3 hrs. One N.C.O., 4 armourers and 4 Africans were employed on this work under the supervision of Dr. Toms, Mr. Fryer and Sgt. Jackson of Porton.

5. Preparations for Trials

(a) All aircraft and M/T vehicles were serviced and personnal taking part in the trial warned, on the day before the trial. Air crews were briefed on the morning of the trial by S/Ldr. Phillips who had previously reconnoitred the area to be sprayed and determined the sites at which smoke signals were to be set out.

Field equipment including meteorological apparatus, food and water, were loaded on the vehicles ready for moving off in convoy to the area by

1A

Preparing Chargings in 45 gall. oil drums. The 900 gall. tanker in the background contained water for emulsion mixtures.

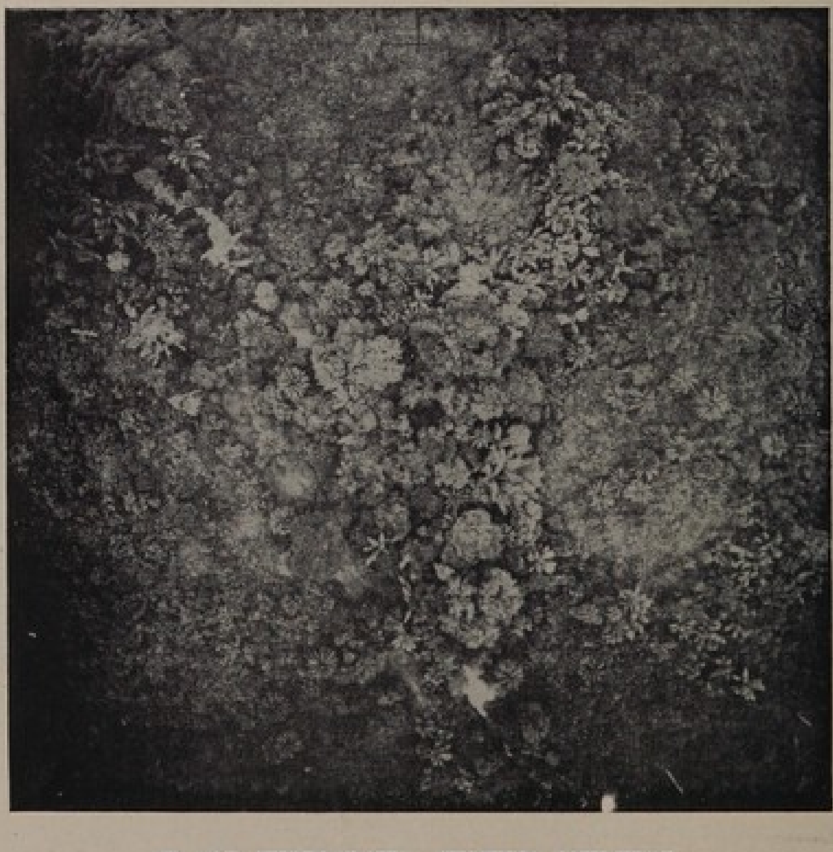
2A

Stirring spray mixture and Charging S.C.I. Two hand operated semi-rotary pumps used for transferring the mixture from mixing tanks to S.C.I. can be seen in the centre foreground.

15

LOWLAND EVERGREEN RAIN FOREST
(The canopy photographed from the air)

16



AN AIR PHOTOGRAPH, SHOWING OVERHEAD
COVER ABOVE A RIVER

0730 hrs. on the day of the trial. Progress to the area was invariably slow on account of bad roads, flimsy wooden bridges (usually in a precarious state) over streams and ditches, and after heavy rain, the roads and tracks were flooded to a depth of 2 ft. in places.

The siting of jump cards, glass plates and entomological equipment in jungle is extremely difficult and exhausting work and cannot be accomplished quickly. These factors had to be taken into account when fixing a time over target for the first sortie of aircraft. Experience showed that for areas 30 or more miles from base, time over target for the first sortie could not be before 1000 hrs. During the interim period between the departure of the field party for the area and the time of take off for the first sortie and subsequent sorties, charged S.C.I. on cradles were placed behind each aircraft at the dispersal points, and two mobile petrol bowsers were sited conveniently near the aircraft. This arrangement reduced handling of charged S.C.I. to the minimum and enabled refuelling and bombing up operations to be carried out quickly and efficiently between sorties. Much valuable time was gained in this way as will be seen from Table I attached.

(b) Aircraft

Throughout the period of the trials, daily serviceability of the 11 Vengeance aircraft available was very rarely below 85%. This is entirely due to the efficiency and keenness of the ground crews who put in some really hard work under trying climatic conditions. The flying technique finally adopted by the flight commander after several experiments, and described in the report, proved entirely satisfactory.

Usually nine aircraft were bombed up, although five per sortie only were used. This necessitated refuelling and rebombing one aircraft of each sortie immediately on return to base, to make up the next sortie - average time for refuelling and rebombing an aircraft was just over 3 mins. The five aircraft in each sortie took off at 20 secs. interval between aircraft and the pilots were at their flight stations three minutes after the last aircraft of the sortie was airborne. Radio communication between aircraft, flying control (base) and the mobile ground station at the area, was maintained throughout the trial. Visual means of communication, e.g. Aldis lamp, Verey light and coloured smoke, were available in case of radio failure between aircraft and mobile ground station.

6. Observers

The following British and American officers attended a few of the field trials and took part in several informal discussions on air spraying of DDT solutions. Individual opinions were expressed freely and without prejudice.

Arrangements were made for each observer to receive a copy of the programme and summary of results of each trial, as and when available.

Major Gen. Brunskill	D.S.W.V. War Office.
Prof. Heilbron	Ministry of Production.
G/C Hill	Medical Adviser to S.A.C., S.E.A.C.
G/C Lipscombe	M.A.A.F. (now P.M.O. A.H.Q.W.A.).
Lt. Col. Stevenson	A.D. of H. G.H.Q. Accra.
Lt. Col. Jameson Carr	Office of D. of H. War Office, London.
" Mackerras	C/O H.Q. Australian Forces, Australia House, London.
" Daniells	H.Q., U.S.A.F. Accra.
" Andrews	2655th Malaria Control Detachment, A.P.O.534, U.S. Army.
Major Farrell	H.Q., U.S.A. Malaria Unit, Accra.
Major James	S.A.A.F. C.W. Adviser to A.C.S.E.A.
Dr. Riehl	H.Q., 2675th Regt. A.C.C. A.P.O.394, U.S. Army.

7. Acknowledgements

There is no doubt that the excellent material facilities afforded to the unit, and the enthusiastic co-operation of the station commander and senior staff officers at Takoradi, were largely responsible for any success which these trials may have achieved.

Table 1

The table below shows times for refuelling and rebombing aircraft and times taken between sorties throughout trials.

Refuelling and rebombing operations were carried out simultaneously.

Five trials only are quoted.

Trial No.	No. of sortie (5 A/C)	Time		Time		Remarks
		Airborne	Landed	On ground	between sorties	
1 (Natiem) (42 miles from base)	First	0955	1115	25 mins.	1 hr. 45 mins.	Owing to minor faults which developed on the aircraft during and between sorties, 3 A/C had to be refuelled and rebombed between sorties instead of one.
	Second	1140	1220	32 mins.	1 hr. 12 mins.	
	Third	1252	1346	26 mins.	1 hr. 20 mins.	
	Fourth	1412	1502			
			Average	27 mins.	1 hr. 26 mins.	
		Total time for trial 5 hrs. 7 mins.				
2 (Ataraso) (30 miles from base)	First	1048	1133	20 mins.	1 hr. 10 mins.	
	Second	1158	1234	20 mins.	1 hr.	
	Third	1258	1342	28 mins.	1 hr. 17 mins.	One aircraft failed to start - rebombed another.
	Fourth	1415	1455			
			Average	23 mins.	1 hr. 9 mins.	
		Total time for trial 4 hrs. 7 mins.				
3 (Awusioja) (20 miles from base)	First	0948	1020	25 mins.	1 hr. 1 min.	Refuel and rebomb 2 A/C. Bad start 2 A/C.
	Second	1049	1115	23 mins.	49 mins.	Refuel and rebomb 2 A/C.
one sq. mile	Third	1138	1208	25 mins.	55 mins.	Refuel and rebomb 3 A/C.
	Fourth	1233	1258			
			Average	24 mins.	55 mins.	
		Total time for trial 3 hrs. 10 mins.				

Table 1 (Contd.)

Trial No.	No. of sortie (5 A/C)	Time		Time		Remarks
		Airborne	Landed	On ground	between sorties	
4 (Asani) (23 miles from base) one sq. mile	First	0852	0927			
				24 mins.	59 mins.	
	Second	0951	1021			
				19 mins.	49 mins.	
	Third	1040	1113			
				22 mins.	33 mins.	
	Fourth	1135	1205			
			Average	22 mins.	47 mins.	
		Total time for trial 3 hrs. 14 mins.				
5 (Ntangufo) (12 miles from base) one sq. mile	First	0952	1022			
				28 mins.	58 mins.	Sortie delayed 6 mins.
	Second	1050	1110			
				20 mins.	50 mins.	
	Third	1130	1157			
				20 mins.	47 mins.	
	Fourth	1217	1248			
			Average	22 mins.	52 mins.	
		Total time for trial 3 hrs. - mins.				

APPENDIX H TO PORTON REPORT NO.2669

The penetration of air sprays through tropical vegetation

by S/Ldr. Phillips, Dr. B. A. Toms and J. W. Siddorn

Introduction

1. In the months July - November, 1944, a series of trials were carried out in the Gold Coast in order to determine the effects of air sprays containing DDT on larval and adult mosquitos. In the course of these trials, data were collected on the penetration of air spray through different kinds of W. African vegetation. The preliminary results thus obtained suggested that the penetration was less than had been anticipated and since it was a subject of importance to all types of air spray, an additional series of small scale trials was carried out to obtain further information.

Material

2. All the sprays were delivered from Vengeance aircraft fitted with American tanks, Airplane M.10, modified by the addition of a 2½" reducing thimble on the emission pipe: the spraying performance of the M.10 tank so modified is almost identical with that of the 500 lb. S.C.I. Mk.III.

3. The DDT/Oil Mixtures Nos. 1 and 2 specified in Appendix D were used in the large-scale air spraying trials over square mile areas of country. Information of a general character pertaining to the filtration of air spray by vegetation of different kinds was obtained in these experiments. For the specialised "penetration trials" an oil mixture (No.3) composed of 15 vols. Gas Oil and 10 vols. Lubricating Oil M.220 (H.D.50) was employed. The properties of these chargings may be summarized as follows:-

Oil Mixture	DDT content (% by weight)	Specific gravity	Viscosity at 25°C. (centipoises)
No.1	0.6	0.86	3.8-3.9
No.2	2.9	0.88	7.4-7.9
No.3	Nil	0.87	ca. 12.5

Concerning the dispersion of these oil mixtures as air spray under the conditions defined in para.9 and in the main report, it may be said that in each case about 80% of the charging was dispersed as drops between 0.2 and 0.6 mm. diameter and almost the whole of the remainder as drops smaller than 0.2 mm. diameter. No drops exceeding 1.0 mm. diameter were found.

About 1% of dye (Williams Spirit Red III) was incorporated in each charging for assessment purposes.

Vegetation

4. The area chosen for the trials is situated about 4½° N. of the equator. A large part of the area is covered with lowland evergreen rain forest. The average height of this is between 130-150 feet (see photo. No.1) and as a rule the canopy consists of three or four layers difficult to penetrate from above, (see photos.15 and 16 attached to this appendix). Compared to rain forests in many other parts of the world, however, there is a scarcity of creepers and bush vines. The bulk of this forest is of secondary growth, but from the point of view of spray penetration there is no reason to differentiate between it and the primary forest.

5. Much of the rest of the area consists of land once cleared for cultivation which is now reverting to the secondary forest mentioned above. This reversion is, of course, gradual, and innumerable intermediate stages exist; for convenience, however, they may be divided into two classes:-

(i) A mass of herbaceous yellow flowered sunflower about 8'-10' high (see photo. No.2) very dense and impenetrable without a knife.

(ii) A mixture of small trees and bush, 15'-30' high, which is almost impenetrable without cutting a path (see photo. No.3, main report).

6. Various specialised areas occurred which fall into four groups:-

(i) Avicennia Mangrove swamp (photo. No.4).

(ii) Freshwater swamp forest (photo. No.5).

(iii) Treeless swamps, densely covered with sedge or rushes.

(iv) Dense bamboo clumps 60'-80' high (photo. No.6).

7. The areas of native cultivation consisted of

(i) Cassava (see photos. Nos.8 and 9).

(ii) Maize (see photo. No.7).

(iii) Coconut and oil palms (see photo. No.7).

(iv) Rice.

(v) Cocoa.

(vi) Bananas.

Of these, (ii) and (iv) had been harvested prior to the trials.

Method of Sampling

8. The various spray mixtures were dyed and were assessed by setting out sampling envelopes. The density of contamination and the drop size was then determined from the known drop-stain relationship.

9. The type of cover required for test was sought for until an area was found alongside a road or other open space. This allowed sampling envelopes to be set out, both under the cover and in the open, equidistant downwind from the spraying track.

Spraying

10. Forward visibility of the Vengeance aircraft is very bad, particularly at speeds below 220 m.p.h. (under this speed the aircraft flies "nose high") and this, together with the broken nature of the country and the presence of tall, single, cotton trees, had two effects on the trials:-

(i) It was impossible to adhere to a standard height/wind product.

(ii) The speed of flight had to be above 220 m.p.h. with a consequent increase in shatter of the charging.

Results

11. It is difficult to give a set of figures relating to penetration of even a single type of vegetation, since the density of leaf cover varied enormously from place to place. The figures quoted here are averages from a number of envelopes, usually from several separate trials, but even so, no claim can be made that they will always apply to the particular type of vegetation sprayed; they are, however, of the correct order of magnitude.

In cases where a type of vegetation varied greatly, a high and a low estimate are both given. The penetration is expressed as a percentage by volume of the contamination which would occur at an identical point were all the vegetation cleared away.

Type of Vegetation	Remarks	Average penetration
Lowland Evergreen Rain Forest.	The penetration naturally varied with the number of layers of the canopy. A clearing surrounded by forest may have as high as 40% penetration.	1%
Secondary Growth		
(i) Dense herbaceous growth 8'-10' high.	The first stage of reverting cultivation.	1%
(ii) Scrub and bushes about 10'-12' high.	Varied between 3% and 7%.	5%
(iii) Secondary woods containing trees about 30' high with scrub underneath.	Varied between about 2% and 5%.	3%
Avicennia Mangrove Swamps.	These varied greatly in density with a consequent penetration variation of 3% - 62%.	21%
Freshwater Swamp Forest.	As above, varying from 3% - 30%.	20%
Fern or sedge covered swamps.	This result is based on a few envelopes only, and should be accepted with reserve.	8%
Dense Bamboo Clumps.		ca. 0.1%
Crops		
(i) Cassava.	Variation (6% - 22%) owing to differing heights of crop. 3' high - about 18%. 8' high - about 9%.	14%
(ii) Maize.	Sowing varies greatly as regards distance between individual plants. Penetration varied between 9% - 20%.	15%
(iii) Banana.	Large individual leaves cause great variations over small areas of ground beneath the trees, i.e. Trace to 23%.	(?)
(iv) Coconut and oil palms.	Small groves with no undergrowth.	25%
(v) Cocoa.	This was a low, dense plantation.	
	(a) Cocoa trees with no undergrowth.	1.6%
	(b) With dense fern cover beneath.	0.1%

Discussion of results

12. Attempts were made to develop some standard methods of evaluating the filtration effect of the canopy; such methods included an estimation of the ratio of clear sky to leaf cover (e.g. 7/10, as for cloud cover), and the use of a photoelectric cell, either pointed vertically upward or used to record the

reflection from a white card. The difficulty arose, however, that, since the spray was not falling vertically but had more or less of a horizontal drift, these figures did not represent the true filtration effect of the vegetation (see photos.8 and 9).

13. Once an air spray has penetrated into lowland evergreen rain forest, it comes into a zone where the air movements are very light and quite indeterminate in direction. It is therefore probable that all but the very finest drops do then fall more or less vertically. This fact had little significance in the W. African forests as ground vegetation was rare, but it may be of importance in forests elsewhere.

14. Under less dense and tall cover than the rain forest, it was found that any additional low ground vegetation greatly enhanced the filtration effect. For example, the penetration through a cocoa plantation with and without additional undergrowth in the shape of masses of fern about two feet high, was as below:-

Cocoa trees, bare ground beneath	1.6%
" " with ferns beneath	0.1%

15. In one trial an area of evergreen rain forest was sprayed by a sortie of three aircraft, each firing two M.10 tanks with 5" emission outlets simultaneously. This should have produced a density of contamination above the canopy of the order of 2000-3000 mg/m^2. An average from seventeen cards exposed on the ground in the forest showed an actual penetration of only 20 mg./m^2, or less than 1% of the total, which agrees very well with the results obtained in trials using a single aircraft with M.10 tanks modified by 2½" thimbles.

16. In all the trials it was noticed that the filtration effect of the vegetation was selective against the larger drops, i.e. a greater percentage of the small drops succeeded in penetrating the cover. This fact is significant in the case of vesicant chargings.

Conclusions

17. The filtration of air spray by vegetation of different kinds is variable and often severe. Where several layers of canopy have to be penetrated, only a very small percentage (about 1%) of the spray is likely to reach ground level.

18. The filtration of air spray by vegetation is selective and is more severe on the larger drops of spray.

APPENDIX I

The Compressibility of Surface Films and the Spread of Larvicidal Oils on Natural Waters in that part of the Gold Coast chosen as the site for DDT Air Spraying Trials

by B. A. Toms

Introduction

1. A necessary quality of larvicidal oils, including those containing DDT, is that they should spread upon natural water surfaces and thus become accessible, over a period of time determined by local conditions, to as large a proportion of the larval population as possible (1). It is by virtue of this property that adequate reduction, and control of larval populations can in practice be achieved by an economical expenditure of oil.

2. Among the factors controlling the size of the oil/water interface which is established by placing an oil drop upon a natural water surface are:

(i) The intrinsic spreading power of the oil as measured by its "spreading pressure" which is the force, in dynes per centimetre, that must be opposed to the advancing edge of a drop, just to prevent it spreading.

(ii) The compressibility of the natural surface film which must be displaced, or pushed back, when (and if) the oil drop spreads. This is measured by the "film pressure", a force equal in magnitude to the "spreading pressure" of an oil which just fails to displace the natural film from the water surface.

3. Of these two factors (i) alone has been extensively studied (2, 3). Concerning (ii) little is known and the existing knowledge is almost all of recent origin (4). Thus, although it has been accepted for many years that a larvicidal oil must spread and that, if necessary, its spreading power should be increased by the addition of a "spread-aider" (3), there have been few attempts to determine an optimum value for the spreading pressure which would ensure that the majority of the natural waters in a given locality can be satisfactorily oiled. Most users of larvicidal oils still carry out a few empirical physical tests with samples of different oils to determine which of them is most likely to meet their particular needs. As a rule this testing involves no more than the placing of a drop of each oil on one or two selected natural water surfaces and/or a rough comparison of its spreading pressure with that of a "standard" specimen of castor oil.

4. Since assessment of the larvicidal action of DDT air sprays constituted a major aim of the West African trials, it seemed desirable to determine, so far as might be possible, their spreading properties when deposited upon the natural waters in the trials area. It was, therefore, decided to investigate

(i) The compressibility of the natural films on waters which could be regarded as typical targets for DDT air spray.

(ii) The spreading pressures of the several DDT air spray mixtures used in the main trials.

The Surface Films on Natural Waters

5. A tough, inelastic bacterial slime is the matrix, or foundation, of most natural surface films. In this are embedded certain other materials which, for convenience, may be classified roughly as "biological" or "chemical" according to their nature. In "biological" films these additional components are mainly bacteria, protozoa, algae and pollen, while in "chemical" films dusts and inorganic colloids, often of a ferruginous nature (5), are the predominant additions to the slime. As might be expected, wholly "biological" or wholly "chemical" films are rarely, if ever, found in nature.

6. Natural surface films, which may be visible or invisible, are thin membranes which form when waters are undisturbed by wind or rain. They have a

certain rigidity and resist displacement by an oil film but even a light wind can cause them to become concentrated at the leeward margins of the water surface.

7. Until recently study of the physical properties of natural surface films has been hampered by a lack of apparatus suitable for use in the field by individual workers. Now, however, there is available a simple, yet accurate and reliable, method of determining the compressibility, or the "crushing strength" of natural surface films. This method can readily be employed under field conditions and made it possible to carry out the present investigation.

The Site of the Experiments

8. Large-scale DDT air spraying trials were carried out in that part of the Gold Coast within five degrees of the Equator delimited by the coastal towns of Sekondi and Axim and extending inland for a distance of about 15 miles. Except for a coastal strip less than a mile wide, there is no flat ground in this area but the hills are all small, and gently sloping, and nowhere exceed 300 feet above sea level. The surface rock is red "laterite", mostly of a clayey consistency, which lies in irregular undulations. This part of the W. African coast received abundant rainfall (see Appendix F) and was at one time covered with lowland evergreen rain forest but, owing to the system of shifting cultivation practised by the inhabitants, this has been almost entirely replaced by "secondary" forest. Considerable areas of land around present or former village sites are either cleared for cultivation or in process of reversion to forest (see Appendix A).

9. The natural waters in this area are many and varied as regards character, size and location. At the time of the experiments (September - November) the countryside was drying with the onset of the annual dry season which lasts from November to April, and much casual water left by the rains of May, June and July had already disappeared. Nevertheless, there remained an interesting selection of natural waters and these were augmented, albeit infrequently, by heavy showers of rain. They included transient rain pools in forest tracks, shallow water-logged irrigation and roadside ditches, borrow pits, streams, slow-flowing meandering rivers, and permanent freshwater swamps of different kinds (see Appendix A). Surface films on all these types were studied, some in considerable detail.

Method of determining the Compressibility of natural Surface Films

10. Adam has described (6) a simple yet reliable method of measuring or comparing the spreading powers of larvicidal oils. This method is a marked improvement on an earlier, though essentially similar, technique (2) in that the determinations are made with "spreading standards" whose spreading pressure is almost unaffected by the normal variations of the temperature and acidity of natural waters. The adaptation of this method to the study of natural surface films may be described briefly as follows:-

11. A series of "spreading standards" i.e. liquids or solutions of known spreading pressure is obtained. Adam recommends that standard solutions of oleyl alcohol, or of terpineol, in liquid paraffin be used and the former were employed almost exclusively in the present investigation. For convenience, the spreading standards are compounded so that the spreading pressures of adjacent members of the series differ by some fixed amount e.g. 5 dynes/cm. A determination of the film pressure on a natural water surface, or on a part of it, is made by placing a drop of the spreading standard having the lowest spreading pressure on the water. If this drop fails to spread a drop of the next (higher) member of the standard series is placed nearby. This orderly procedure is continued until a solution is found which can just displace, or push back, the natural surface film. The appropriate film pressure then lies between the spreading pressure of this standard solution and that of the preceding, lower member of the series which just failed to spread on the water surface.

The Spreading Standards used in W. Africa

12. Although standard solutions of oleyl alcohol and of terpineol in liquid paraffin were available, only the former were used generally as they

seemed to give the most consistent results both in the field and in the laboratory. These spreading standards had been prepared at Porton using

(i) Oleyl alcohol (Iodine Value = 61.8) made by I.C.I. (Dyestuffs) Ltd.

(ii) Liquid Terpineol, made by B.D.H.

(iii) Liquid ("Medicinal") Paraffin (S.G. = 0.835/0.850), made by B.D.H.

NOTE: (i) and (ii) were supplied by Prof. N. K. Adam, F.R.S., University College, Southampton, and were samples of the materials described in his recent paper (6).

13. In detail, the compositions of the chosen spreading standards were as follows:-

Series A: Oleyl Alcohol/Liquid Paraffin solutions

Solution No.	Concentration (g. Oleyl alcohol per 100 ml. solution)	Spreading Pressure (dynes/cm. at 20°C.)
1	0.15	10
2	0.35	15
3	0.60	20
4	1.0	25
5	2.0	30
6	3.9	35
7	6.5	40
8	10.0	46

Series B: Terpineol/Liquid Paraffin solutions

Solution No.	Concentration (ml. Terpineol per 100 ml. solution)	Spreading Pressure (dynes/cm. at 20°C.)
1	0.10	5
2	0.30	10
3	0.65	15
4	1.5	20
5	5.0	25
6	10.0	30
7	Pure Terpineol	36

14. By means of these spreading standards the film pressures obtaining on natural waters could be determined and classed in the ranges 0-5, 5-10, 10-15, ... 40-45, and greater than 45 dynes/cm. Thus a film allocated to the "30-35" class was of such rigidity that solution No. 5 (Series A) just failed to push it back but solution No. 6 of the same series displaced it, either partially or almost completely, from the water surface.

15. For use in the field the spreading standards were stored in 1 oz. brown glass bottles each fitted with a cork carrying a short length of thin glass rod which dipped into the liquid. The bottles were carried in a small wooden case with partitions inside to keep them upright and apart.

Results

16. It soon became apparent that, from the physical stand-point, the films on natural waters in the trials area, were of two distinct types which may be designated Uniform Films and Non-Uniform Films. When a uniform film was present, very nearly the same film pressure was recorded in all parts of the water surface but if the film was of the non-uniform type considerable differences were observed among the film pressures determined in different places on the surface even though these were sometimes no more than 6-12 inches apart.

17. Substantially uniform films were detected on all waters whose surface could be described as "clean" (i.e. free from visible scum of any kind when examined by reflected light) though in some cases the water was turbid. Non-uniform films were frequently, if not always, found on waters where a surface scum of some kind was clearly visible. It was of particular interest and importance to find that if a part of a water surface was segregated from the rest by some natural obstacle (e.g. floating twigs, debris, weeds, algae, mud) films having quite different properties could exist on either side of the barrier or at different distances upstream of a barrier athwart flowing water.

18. These findings may be illustrated by the following examples:-

(i) Uniform Surface Films

Case 1. A large pool (Area: 25 sq. yds., Depth 1-3 feet) surrounded by grass but open to the sky. The water was clear and brown algae could be seen at the bottom. The surface was studded with water-lilies but was clean in the spaces between the leaves. The film pressure was determined at 24 separate places around the periphery of the pool.

Film Pressure (dynes/cm.)	Number of Observations
0 - 15	0
15 - 20	3
20 - 25	18
25 - 30	3
>30	0

Case 2. A large (3-5 acres) freshwater swamp with Palms growing in it. Between the trees, which formed "islands" in the swamp, the water was muddy and about 2 ft. deep with tangled leave and branches at the bottom. The surface, however, was comparatively clean. The film pressure was determined at 19 separate places scattered through the swamp.

Film Pressure (dynes/cm.)	Number of Observations
0 - 5	0
5 - 10	1
10 - 15	15
15 - 20	1
20 - 25	2
>25	0

(ii) Non-uniform Surface Films

Case 1. A bamboo grove with a stream (6-9 ft. wide, 6-18 inches deep) flowing slowly through. At one point some large bamboo canes had fallen athwart the stream causing a blockage. A large pool covered with gelatinous bubbly scum had formed on the upstream side of this barrier and the water escaped underneath. Further upstream the stream was crystal clear, with a clean surface and a soft mud floor. The film pressure was determined in mid-stream at measured distances upstream of the dam.

Distance up-stream from barrier (feet)	0	2	4	6	8	10	12	14	20
Film pressure (dynes/cm.)	>45	>45	>45	35-40	20-25	15-20	10-15	5-10	5-10

Case 2. An inland Avicennia swamp from which the seepage flowed into a large river nearby. The floor of the swamp was composed of soft mud flooded to depths of ranging from 3 inches to several feet in different places. Where the water was shallow mud and young mangrove shoots contrived to break up the water surface into discrete patches: a similar segregation was occasionally found in deeper water where floating debris had become knit into a tangled mass. The film pressure was determined at 45 separate places scattered at random over the accessible parts of the swamp.

Film Pressure (dynes/cm.)	Number of Observations
0 - 5	0
5 - 10	6
10 - 15	15
15 - 20	6
20 - 25	6
25 - 30	8
30 - 35	2
35 - 45	0
>45	2

Frequency Analysis of Film Pressure Observations

19. The information summarised in paras.15-17 established that:-

(i) The compressibility of uniform surface films varied from one site to another but was almost constant at one site.

(ii) The compressibility of non-uniform surface films varied from point to point at a single site.

Generally, the variations observed in (i) were much less pronounced than those encountered in (ii). It was not possible to determine directly whether uniform films were more or less common than non-uniform films as the time available would not permit of visits being made at random to a sufficient number of sites. On general grounds, however, it did not seem necessary to embark on such a task for it was argued that since air spray distributed more or less uniformly over a large area of country (ca. one square mile) will be deposited upon waters of all kinds it would be more pertinent to discover the frequency-distribution of the film pressures likely to be encountered by drops falling on water in random pattern. It should then be possible to determine an optimum value for the spreading pressure of the DDT spray mixture such that a majority of drops might be expected to spread on the waters in the trials area.

20. With this end in view the results of 323 separate and random determinations of the film pressures on natural waters, comprising measurements made at about 50 different sites, and at one or more places in each site, were analysed:-

Film pressure (dynes/cm.)	Number of cases observed	% of cases in stated group
0 - 5	0	0
5 - 10	62	19.2
10 - 15	67	20.7
15 - 20	23	7.1
20 - 25	43	13.3
25 - 30	59	18.3
30 - 35	11	3.4
35 - 40	5	1.6
40 - 45	9	2.8
>45	44	13.6
TOTALS:-	323	100.0

21. From this analysis it can be deduced that about 80% of the observed film pressures were less than 30 dynes/cm. and that most of the remainder exceeded 45 dynes/cm. Generally, the latter pressures were detected here and there on waters whose surfaces were fouled with visible patches of scum of different kinds while the former were recorded on "clean" areas of surface.

Discussion

22. These findings are both interesting and important for they indicate the spreading power required in a larvicidal oil intended for application to the waters in a particular area of the Gold Coast. Thus, while it would be extremely difficult in practice to ensure that oil drops will spread upon water surfaces, or those parts of them, where the film pressure exceeds 45 dynes/cm., it is relatively easy to increase the spreading pressure of a mineral oil to 25-30 dynes/cm. Such an oil, as the results in para.21 show, will spread in the vast majority of the sites investigated in the trials area. In this connection it may be observed that the spreading pressures of the DDT air spray mixtures (Appendix D) used in the W. African trials were as follows:-

(i) DDT/Oil mixtures: 28-30 dynes/cm.

(ii) DDT Emulsions: 46 dynes/cm.

The spreading pressure of the mineral oils used in compounding (i) were of the order of 15 dynes/cm. and this was increased to >25 dynes/cm. by the addition of about 0.5% commercial oleic acid. The spreading pressures of the spray mixtures were determined by the "overflowing funnel" method described by Adam (6).

Conclusions

23. This survey of the film pressures obtaining on the surface of natural waters in that area of the Gold Coast where large-scale DDT air spraying trials were carried out during September-November has shown that these waters fall into two main groups:-

(i) Those with film pressures less than 30 dynes/cm.

(ii) Those with film pressures greatly in excess of 45 dynes/cm.

In both groups, but almost exclusively in (ii), there are surface films of a markedly non-uniform character whose compressibility varies from place to place.

24. Assuming that in each trial the DDT air spray was more or less uniformly distributed over the target area it would appear likely that at least 75% of the drops of each of the spray mixtures used must have spread when they impinged on a natural water surface.

Summary

25. An investigation of the compressibility of the surface films on natural waters in an area of the Gold Coast is described. The significance of the results obtained in relation to the spread of drops of DDT air-spray released over this area of country is discussed.

Acknowledgment

26. The spreading standards specified in para.13, were prepared by N. Moss, Chemistry Section, Porton.

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The Physical Methods used to study the deposition of DDT Air-Sprays upon selected areas in W. Africa

by B. A. Toms

1. Subordinate, but complementary to the main aims of the trials, was the collection of relevant physical data concerning the behaviour of air spray when discharged over (i) areas of wet, tropical forest and cultivated land, and (ii) native dwellings.

2. It was considered that entomological observations of the larvicidal action of DDT air spray might usefully be augmented by determination of -

(i) The sizes, area distribution and spreading of spray drops impinging on the surface of water in which a larval population was under observation.

(ii) The approximate dosage of DDT (pure) and of spray liquid producing an observed larvicidal effect.

(iii) The causes of any significant local variations in the larvicidal action of air spray which had been distributed more or less uniformly over a large area of country (e.g. one square mile).

3. Concerning the effects (if any) of DDT air spray against populations of adult W. African mosquitos, the requisite physical data could not be defined at the time of inception of these trials since the mode of action of coarse air-spray against these insects was unknown. In that connection, however, it may be observed that two dominant views were then held, viz that adult mosquitos could be killed either by contact with falling spray drops while in flight or by alighting on contaminated surfaces (foliage, thatch, etc.) after spray had fallen. Alternatively, it was possible that killing might be accomplished in practice by both methods.

4. In view of the foregoing it seems desirable, (i) to describe the methods of field assessment employed in the W. African trials, (ii) to discuss, in general terms, their intrinsic suitability for the purposes mentioned and their efficacy when used under the conditions of climate and terrain which prevailed in the trials area.

The Study of Air Spray

5. Until spraying of DDT from the air was undertaken, coarse air spray, of the kind produced by present service equipment, had been studied almost exclusively from the chemical warfare standpoint. Thus the contamination of ground and objects thereon constituted a major requirement for operational purposes. For these reasons, the physical and chemical methods of field assessment in current use at Porton and elsewhere were designed to provide information concerning:-

(i) Those factors which control the dispersion of a liquid by aerodynamic forces.

(ii) The dispersion and distribution of the liquid achieved under specified conditions of air spraying.

Summation of the many data sought under these heads serves to define, from the physical standpoint, the 'performance' of C.W. air spray when directed against a specified target under fixed conditions.

6. Concerning the performance of DDT air spray it was decided that although larval and adult mosquitos constituted new and peculiar targets for air spray the collection of similar data, by the same methods, should be undertaken in West Africa. It was recognised, of course, that the conditions of climate and terrain in the trials area might hamper experimental work in the field and that the interpretation of any results obtained would inevitably be complicated, and might be confused, by the unusual conditions of air-spraying.

In particular, the insertion of a natural filter of unknown efficiency (i.e. the "vegetational canopy, or screen") between the air spray and its proper, though ill-defined, targets was considered to be of unique and overriding importance. It seemed likely that this spray filter would have a two-fold action for in addition to a (? selective) trapping of falling drops of different sizes, the movements of any very small drops which entered the interstices of the canopy would be controlled by such special meteorological conditions as might prevail there. Generally, therefore, it seemed possible that the forces determining the primary distribution of DDT air spray immediately after its release from an aircraft might differ, both qualitatively and in order of magnitude, from those producing the secondary, or final, distribution of the spray on its targets.

Review of the Physical Methods, and Results, of Field Assessment of DDT Air Sprays in West Africa

7. The magnitude and complexity of the field sampling problems deriving from each of the prepositions outlined in paras.2, 3 and 6, coupled with the contemplated duration of the W. African trials and a severe limitation of the number of personnel skilled in such work, dictated that only those data which could be obtained quickly, by simple methods, could be sought.

The Working Conditions

8. While a considerable amount, and variety, of laboratory apparatus and field equipment was taken to Takoradi by the Porton Team, arrangements had fortunately been made to augment these stores locally and also to enlist the help of resident expert personnel when necessary. Thus, the R.A.F. Station Meteorological Office undertook to determine all standard meteorological data relevant to the trials leaving only minor and specialised observations to be made by the Porton personnel. Much photography, and all developing and printing, were carried out by the local R.A.F. Unit.

9. Satisfactory laboratory accommodation (including electricity and water supplies), for carrying out physical and chemical experimental work pertaining to the manufacture and properties of DDT air sprays, and the examination of samples collected in the field, was installed in a part of the M.I. Room on the airfield.

10. Two members of the Porton team were directly concerned with all aspects of the assessment work undertaken. In the field they were assisted by willing, though unskilled, Africans. Fortunately, however, part of the work in the large-scale trials was taken over by the entomologists who placed sampling devices at the sites in which they were specifically interested. The heat and high relative humidity, coupled with the physical effort of forcing a passage through bush and swamps and of walking long distances in rubber boots, made protracted spells of field work exhausting for Europeans not long acclimatised to W. Africa.

The Field Sampling Apparatus

11. The following devices were available for studying the performance of DDT air sprays in the field:

(i) Absorbent paper squares ("Sampling envelopes") mounted on thin card.

(ii) Glass plates ($3\frac{1}{4}$" x $4\frac{1}{4}$") coated on one side with magnesium oxide.

(iii) Plain glass plates ($3\frac{1}{4}$" x $4\frac{1}{4}$").

(iv) Two series of standard solutions (oleyl alcohol/liquid paraffin and terpineol/liquid paraffin) of known spreading pressures. (See Appendix I.)

12. Concerning (i), (ii) and (iii), all of which were used to collect samples of fallen spray, it may be recorded that -

(a) Plain glass plates were used in those trials where the air spray was DDT Emulsion which could not be characterised with dye (see Appendix E). They served to demonstrate whether or not spray had fallen at selected sites but yielded no quantitative data.

(b) Sampling envelopes were used in those trials where the air spray was a dyed DDT/Oil mixture. They served to demonstrate whether or not spray had fallen at selected sites but, in addition, they yielded data concerning the nature and density of the surface contamination. The high relative humidity obtaining in W. Africa rendered these envelopes permanently moisture-sodden and limp; in many cases the absorbent paper became detached from its card backing.

(c) Glass plates coated with magnesium oxide (which were made as required) had the same general function as (b) but offered the considerable advantage that they could be used to sample undyed air sprays such as DDT emulsions. In fact, however, the plates were seldom employed because their preparation was so time-consuming and they proved so fragile being completely ruined by even light rain or drips from wet foliage.

Summary of the Results obtained in Field Experiments.

Assessment of Dyed DDT/Oil Air Sprays

13. (i) In small-scale trials (Appendix E) where air spray could be released under definable conditions, the drop-spectra and 'primary distribution' (on open, level ground) of these spray mixtures were determined in some detail though on no occasion was it possible to deal with droplets smaller than about 0.1 mm. diameter.

(ii) In none of the large-scale trials (square mile target areas) was it possible to observe primary distribution of air spray over the surface of the 'vegetational canopy', nor could this be deduced since the relevant height-wind product was unknown. However, it was usually possible to determine, by visual examination of contaminated foliage, whether or not the spray had been distributed more or less uniformly over the whole target area. In certain cases these observations were confirmed by examination of envelopes at sites open to the sky, e.g. along roads.

(iii) The nature and amount of spray deposited upon selected sites (all at ground-level) could be determined with considerable accuracy by examination of contaminated envelopes at these sites. In many cases, however, the envelopes were ruined as sampling devices by wetting with rain or by heavy drips from wet foliage overhead. The information obtained concerning the penetration of air spray through foliage of different kinds is described in Appendix H.

Assessment of Undyed DDT Emulsion Air Sprays

14. No quantitative data were obtained concerning the performance of these air spray mixtures. In large-scale trials the presence or absence of fallen spray at a given site was sometimes detected by means of glass plates, but more often by visual examination of contaminated foliage, etc., which also served to show whether or not the spray had been distributed more or less uniformly over the whole target area.

Comments on the Results Obtained

15. In the INTRODUCTION (para.1) it was stressed that while the collection of physical data was a subsidiary aim of the W. African trials such information would not only have an intrinsic value, but might serve to elucidate, or to augment, the entomological observations. While the intrinsic worth of the physical data obtained is beyond question it is of interest to discover to what extent they supplemented the biological findings. A summary of the correlation achieved may be presented as follows:-

(i) The larvicidal action of DDT Air Spray

In trials with dyed oil spray mixtures it was possible to determine the dosage and distribution of DDT which caused an observed larvicidal action (e.g. complete kill, partial kill, or failure to kill) in a selected breeding place. Variations in the larvicidal action achieved in different breeding places, or in different parts of the same (large) breeding place, were shown to be due to the variable (though usually drastic) filtration of air spray by vegetation of all kinds. Less complete information was obtained, on the physical side, in regard to the larvicidal effects achieved in flowing waters though it was clearly demonstrated that the (unknown) dosage to which larvae in such places were subjected was a combination of (a) spray which had fallen directly upon the site and (b) DDT/Oil solution (film) carried thither by the current. Useful information concerning the spreading of oil mixtures and emulsions on natural water surfaces was also obtained (see Appendix I).

(ii) The effects of DDT Air Spray against adult mosquito populations

In trials with dyed oil spray mixtures it was possible to demonstrate that

(a) A variable, though usually large, proportion of air spray was deposited upon foliage, thatch, etc.

(b) Only a very small amount (mass) of air spray drifted through openings into the interiors of even flimsily-built native dwellings.

(c) In the absence of other than small convectional air currents the deposition of substantial amounts of spray around wire gauze cages containing active adult mosquitos failed to kill the insects.

No measure of the dosage of DDT required to kill an adult mosquito was obtained nor was there any direct evidence as to the manner in which adults were killed by air spray though it seemed most probable that contact with contaminated surfaces, during night flying after spray had fallen, was the predominant cause of the deaths observed in the W. African trials.

Conclusions

16. In the W. African trials certain physical data pertaining to the performance, as air sprays, of dyed DDT/Oil mixtures were obtained by means of simple field sampling apparatus. The facts established served to elucidate, both qualitatively and quantitatively, many of the entomological observations concerning the larvicidal action of DDT/Oil air spray under W. African conditions but were of qualitative value only in relation to the action of the spray against adult mosquito populations.

17. No quantitative assessment of the performance of undyed DDT Emulsion air sprays could be made but the qualitative aspects were adequately covered by information derived from the detailed study of dyed oil mixtures sprayed under similar conditions.

Summary

18. The means taken, in the W. African trials, to obtain information of a physical character which might augment, and aid the interpretation of, entomological observations pertaining to the effects of DDT air sprays on populations of larval and adult mosquitos are described. The results obtained and the adequacy of the air spray sampling methods, when adapted for use in W. Africa, are reviewed and discussed in general terms.