Preliminary Observations on the Effects of Insecticide Application on the Aquatic Fauna of the Okavango Delta

A. RUSSEL-SMITH, Centre for Overseas Pest Research, London

Introduction

Early in 1974 the Botswana Government approached the British Ministry of Overseas Development with a request for assistance in monitoring the potential side-effects of aerial spraying for tsetse fly control in the Okavango Delta. As a result, the Centre for Overseas Pest Research was asked to organise a small team of biologists to investigate possible effects during spray trials in 1975 and 1976. In the event delays in the arrival of both equipment and staff for the project resulted in a very limited programme of work during the 1975 spraying season. The results reported here are, therefore, of a preliminary nature and are liable to extensive revision during the course of the project. The purpose of this paper is to place our work in a more general context and to outline future investigations in the light of the limited data so far available. The work of the tsetse fly control unit is described elsewhere in this Symposium (Davies and Bowles, 1976), and it will be assumed that the reader is familiar with the contents of that paper.

The effects of insecticides on aquatic animals

An enormous literature on the effects of insecticides in fresh water now exists, and it is not possible to review this in the short space available here. The writer will, therefore, confine himself to describing the types of effects that have been reported, with examples from other fresh water systems. In general, the effects of insecticides can be divided into those that are intended, such as the control of vectors of diseases of man and his domestic stock, and, on the other hand, those that are unintended. The latter includes the killing, directly or otherwise, of non-target animals or plants, the accumulation of residues of the more persistent compounds in the environment and the selection of strains of pest insects which are resistant to one or more insecticides. While a great deal of the literature has, in the past, concentrated on such unintentional effects, it is worth bearing in mind that the intended effect can have as great, if not greater, impact on ecosystems as a whole. More specifically, the eradication of tsetse fly from the Okavango could have an impact at least as great as any unintended effects of insecticides on the fauna. However, since our work is concerned only with direct side-effects, further discussion will be confined to these.

That insecticides can and do kill animals other than the target species is by now well established. However, the significance of this mortality, in ecological terms, will depend on the long-term effect of the insecticide on the population concerned and in very few cases has this been adequately studied. A great deal of our knowledge in this field comes from work done in the United States in connection with aerial spraying for the control of forest pests. For example, it is reported that coho salmon were almost totally eliminated in many rivers in British Columbia after aerial application of DDT at the rate of 1,12 kg/ha, while in the Miramichi River in New Brunswick, young salmon were eliminated following spraying with DDT at 0,55 kg/ha (President's Scientific Advisory Committee, 1963). Similar effects have been reported for freshwater invertebrates. In the Yellowstone River area in the USA, application of

1,12 kg/ha of DDT resulted in an estimated 90% kill of bottom-living invertebrates, although on this occasion no fish mortality was observed (Cope, 1961). Such examples could be multiplied many times and it is clear that the organochlorine compounds in particular are very toxic to aquatic animals. On the other hand, laboratory studies have shown that the toxicity of even closely-related insecticides can differ considerably and that the toxicity of a given compound varies according to the species of animal studied. Thus, in general, Endrin, Toxaphene and Endosulphan are highly toxic to most fish, while other organochlorine insecticides, such as Chlordane, Methoxychlor and Lindane are about 100 times less so. Likewise, in a study of the toxicity of a range of different organochlorine compounds to seven species of freshwater fish, it was shown that differences of up to 20-fold in the sensitivity of the different species to a given insecticide were to be expected (Tarzwell, 1963). It is such a feature that makes predictions about the effects of insecticides in general in the field almost impossible.

It was not until the late 1950s that it was realised that animals were able to accumulate residues of persistent insecticides at levels far above that of the water they lived in and that there was apparent accumulation of such residues along food chains. An early study on Clear Lake in California provides an excellent example (Hunt and Bischoff, 1960). The lake was treated with DDD, an insecticide closely related to DDT, for the control of midges. Five years after treatment, which gave an initial concentration of 14 ppb of the insecticide in the water, no residues were detectable in water or mud. However, in plankton the concentration was 265 times that originally applied, in fish fat from 12 500 times to 135 000 times that applied, and in Western Grebes 80 000 times that applied. The Grebes contained an average of 732 ppm of DDD in the body fat, and as a consequence, showed a sharp decline in numbers as a result of infertility. After discontinuing further treatment with DDD, the Grebe population has now recovered to its original level. A more recent study, involving a coastal saltmarsh in the USA treated with DDT, is perhaps of greater relevance to the Okavango situation (Woodwell, et al, 1967). The soils of this saltmarsh contained an average of 14,6 kg/ha of DDT. In the water the level was about 0,00005 ppm, in plankton 0,04 ppm, in shrimps 0,16 ppm, in fish 1,24 ppm and in gulls and terns from 3 to 75,5 ppm, depending on the species. Thus, the birds contained approximately 10 000 to 1 000 000 times the amount of insecticide in the water. The accumulation of residues in this way depends on the fact that many of the organochlorine compounds are relatively stable and are absorbed selectively into the fat of animals where they remain unchanged for considerable periods of time. Only when fat reserves are drawn upon, for example, during cold periods or during migration, is the insecticide released into the bloodstream, and its toxic effects manifest themselves. While there is some controversy on the exact mechanism by which animals at the end of food chains acquire heavy residue burdens, it is clear that such a mechanism exists and that there is a real hazard to predators in areas treated with low levels of persistent compounds.

The continued use of one insecticide, particularly if it is persistent, can result in the selection for resistant strains of the target insect. Resistance to virtually all the insecticides that have been in wide-scale use for the past ten years has been reported for many pest species. Most work has concentrated on house-flies and mosquitoes, and it is claimed that it is extremely difficult to find strains of the house-fly that show no resistance at all to DDT and that many populations of *Aedes* mosquitoes also show such resistance. Resistance to one insecticide can also confer some degree of protection against related compounds. Continued use of a single insecticide over a long period of time can, therefore, result in the creation of even greater pest problems in the long run.

The insecticide Endosulphan

Endosulphan (also known as Thiodan) is an organochlorine compound and therefore related to such insecticides as DDT, Dieldrin and Aldrin. It differs from these in one important respect, however, in that it has a relatively low persistence both on plants and in animals and water. For example, on Alfalfa crops treated with Endosulphan at the rate of 0,28 kg/ha over 99,9% of the total residues detected was lost, either by degradation or evaporation, 28 days after application (Holsing, 1964). Cattle fed with 10 ppm Endosulphan for 30 days eliminated 99,95% of the residual insecticide within 20 days of the end of the feeding period (Holsing, 1964). In water, breakdown appears to be even more rapid, 99% of the insecticide being degraded in periods varying from one to 21 days, depending on the amount applied and the temperature of the water (Gorbach, et al, 1971). It is somewhat more persistent in soil, and in one test it took 100 days for residues to fall from a level of 0,55 ppm to a level at which they were undetectable (Maier-Bode, 1968).

The relative toxicities of Endosulphan, DDT and Dieldrin, all of which have been used for tsetse fly control in the Okavango, are shown for different groups of animals in Table 1 (data from various sources). The figures given are LD50 or LC50 values and represent the median values for a number of different species, in each case expressed in parts per million.

TABLE 1

The relative toxicities of Endosulphan, DDT and Dieldrin to various groups of animals

Insecticide	*Mammals*	*Birds*	*Fish*	*Tsetse flies*
Endosulphan	100	410	0,015	0,06
DDT	175	600	0,020	0,75
Dieldrin	50	46	0,035	0,10

It can be seen from these figures that while both Endosulphan and DDT are relatively less toxic to mammals and birds than Dieldrin, all three insecticides are highly toxic to both fish and tsetse flies. In particular, Endosulphan shows the highest toxicity to fish and it also has a high toxicity to aquatic invertebrates.

Originally, concern over aerial spraying in the Okavango was centred on possible harmful effects on game and bird populations. However, consideration of the figures in Table 1, in conjunction with the very low rate of application of Endosulphan used (6 g/ha in 1975), suggested that no immediate mortality was to be expected in these groups. Clearly, however, both fish and the aquatic insects that many fish feed on are potentially at risk, as are non-target insects in general. It was decided to concentrate investigations on the one hand on the aquatic fauna and on the other on the terrestrial insects. A brief account of the work on the aquatic fauna during the 1975 spraying season follows.

Studies on aquatic fauna

(a) *Fish:* Unfortunately the ODM fisheries' biologist did not arrive in Botswana until the end of October 1975, after the spraying season was over. However, during this period the UNV fisheries' biologist attached to the project carried out a survey using gill nets in a shallow lagoon at Shorobe, inside the 1975 spray block. Gill nets have the disadvantage that they are highly selective in both the species and size of

fish caught. Since, on the other hand, this was the only effective technique available at that time, it was thought advisable to obtain some limited data using it. Some of the data from this survey is shown in Fig. 1, which gives the total numbers of fish caught in 50 m long nets of two different mesh sizes. Between the pre-spray samples taken in June and those taken prior to the second spray cycle in July, numbers of fish caught in the 25 mm mesh net (first column) fell by 70%. The largest part of this reduction was due to a considerable fall in the numbers of *Schilbe mystus*, a surface and pelagic predator. No *Schilbe* were taken in the 50 mm mesh net (second column), and here the numbers fluctuated in an irregular manner. Immediately following the final spraying in September, the numbers caught in both nets increased to a higher level than that before spraying commenced. Following the first, second and fifth spray, careful searches were made in the lagoon for dead fish. However, at no time during or after the 1975 spray season could dead fish be found. It is suggested that the fluctuations of numbers of fish caught in gill nets was as likely to be due to either movement of fish into and out of the lagoon with the flood waters or to selective removal of *Schilbe* by the gill nets as to any effect of the spraying.

During the third spray cycle a test was carried out on the survival of top minnows *(Aplocheilichtys sp.)* in the water of sprayed and unsprayed lagoons using cages of fine nylon mesh completely immersed in the water. This species was chosen since it is a surface-living form which might be expected to show any effect of the spray fairly rapidly. During the test, which lasted for 24 hours after spray application, no significant difference in mortality between fish in sprayed and unsprayed waters was observed and the surviving fish all appeared healthy.

From the results above, it was tentatively assumed that direct mortality of fish was unlikely at the rate of application of the insecticide used in 1975. However, possible sub-lethal effects of the insecticide on growth, reproduction or feeding have yet to be investigated. Since the beginning of 1976, regular sampling with the beach-seine net described elsewhere in this Symposium (Fox, 1976) has been carried out. This has the advantage of being non-selective in the species and size of fish caught, and also of sampling a known area in such a way that estimates of fish standing stocks can be made. Future work on fish populations will be based on seine-netting as the main sampling technique.

(b) *Aquatic invertebrates:* At the outset of the project it was hoped that work on freshwater invertebrates would focus on the bottom fauna of shallow lagoons and that this work would be correlated with studies on the feeding behaviour of insectivorous fish. However, the study of benthic faunas presents a number of problems, not least the labour of processing the large number of samples required to obtain accurate population estimates. Apart from some preliminary samples from shallow floodplains, no work of this nature was carried out in 1975. Attention was concentrated on surveying the aquatic fauna present and on a brief study of invertebrate drift in a stream in relation to insecticide application. It has been shown elsewhere that the rate of invertebrate drift in rivers and streams is increased by the presence of insecticides in the water, and that this increase is directly proportional to the concentration of the substance in question. A study of the rate of invertebrate drift before and after spraying can, thus, give a reasonably sensitive indication of any disturbance to the invertebrate community of the stream. Sampling for this purpose was carried out in a small tributary of the Thamalakane River that drained from the 1975 spray block. A net with a mouth area of 0,5 m^2 and a mesh width of ca. 2 mm was used and samples were taken at night for two days before the fourth spraying and two days after (Table 2). It can be seen from these figures that while considerable variations in the drift rates of the major groups of animals are observed on consecutive nights, these do not appear to be directly related to the application of the

insecticide. It should be noted in passing that the freshwater shrimp *(Caridina africana)* is an active swimmer and not, therefore, part of the "drift" proper. The results obtained here are indicative only both because the mesh size of the net used was somewhat coarse for the purpose, and also because it would be necessary to carry out studies over a considerably longer period to obtain a true picture of "normal" drift rates. Be this as it may, they do at least indicate that no dramatic effect of the insecticide is likely at concentrations presently used.

TABLE 2
Drift rate of invertebrates in the Boronyane stream before and after spray cycle IV.
Figures are numbers trapped per hour

Group	*Day before or after spraying*				
	−2	*−1*	*0*	*+1*	*+2*
Decapoda *(Caridina africana)*	5,8	0,7	0,7	0,5	1,9
Trichoptera larvae *(Oecetis sp.)*	4,7	2,3	1,8	1,3	4,0
Ephemeroptera larvae	3,0	5,3	4,0	1,8	10,5
Diptera larvae *(Simuliidae)*	2,2	1,0	5,7	0,3	3,4
Chironomidae	1,3	2,0	3,0	0,7	1,2
Other groups	0,8	0,7	0,8	0,8	0,7
	17,8	12,0	16,0	5,4	21,7

Pesticide residues

The analysis of Endosulphan residues from ultra-low-volume spraying presents considerable technical problems, both because the initial amount applied is very small and because the rate of breakdown is extremely rapid. For these reasons, samples of water and fish, after extraction of the insecticide residues in Botswana, have had to be sent to Europe for analysis. While this system has the disadvantage that there is a considerable time-lag between taking the samples and obtaining the results, it does at least ensure accuracy.

During 1975 water samples were taken from Shorobe lagoon before and after spraying in the second, third and fifth cycles. Fish were sampled from the same site before and after spray cycle one, immediately after the last (fifth) spray cycle and 15 weeks after all spraying ceased. Unfortunately, the extracts from the water samples taken during spray cycle three and five were destroyed in transit to Germany, and results are not available for these periods. The results from the second spray application (Fig. 2) do, however, give a preliminary indication of residue concentrations immediately before and after spraying. Included on this graph are comparable data from work carried out in Indonesia on Endosulphan residues in the water of rice paddies following aerial spraying (Corbach et al, 1971). In this area, Endosulphan was applied at approximately ten times the concentration used in the Okavango Delta and the initial residue levels were correspondingly higher than those found in

our studies. It can also be seen that the initial rate of breakdown of the insecticide was much greater in the water of the paddy fields than that of Shorobe lagoon with 99% of the inseciticide degraded within 24 hours. This may have been a result of the much higher water temperatures in the rice paddies, which were, on average, 12°C higher than those of the Okavango during the winter months. The dotted line on the graph represents an extrapolation of our own figures from the residue levels at 4,5 days post-spraying to those found just before the second spray cycle (0,00004 ppm). It is hoped that further data on actual rates of degradation will be obtained during the 1976 spraying season.

As might be expected, it was found that the concentration of insecticide was higher in the immediate surface layers of the water, being about 11% lower at 30 cm depth than at the surface immediately after spraying. This difference was not detected 4,5 days after spraying and this was presumably due to the normal mixing processes found in shallow waters. The results also suggested that the breakdown rate was slightly higher at the surface than in deeper layers with a 22% loss in total residues over the 4,5 days after spraying, compared with only 11% loss at 30 cm depth. Over this period, Endosulphan sulphate, the first-stage breakdown product of the insecticide, increased from 51% to 79% of the total residues. While considerably more work on this aspect of the studies will be needed these results do show that the residue levels to be expected are very low. A search of the available literature reveals that the maximum concentration observed (0,00069) is well below the LC50 values for nearly all species of fish, for which results are available. Samples were taken at Shorobe lagoon of three species of fish with different feeding habits: *Clarius* (barbel), a benthic omnivore, *Serranochromis* (bream), a benthic predator and *Schilbe* (Silver Barbel), a pelagic predator and insectivore. At each sample five specimens of each species were taken and analyses performed on the viscera, muscle and extractable fat separately. The results from the spraying season (June-September 1975) are shown in Table 3. Figures are given as mean concentration of total residues in parts per million of wet weight of tissue for each species. Figures in brackets represent the percentage of the total residues present as Endosulphan sulphate in each case. Figures from the sample taken in December 1975 are not yet available.

As would be expected, residues were not detected before spraying commenced, but within 2,5 days of the first spray application, average levels of total residues ranged from 0,01 to 0,02 in muscle and 0,2 to 2,4 in fat. However, in the sample taken three days after the final spray, residue levels had fallen except in the case of *Schilbe mystus*, where average levels were doubled in the muscle tissues and increased ninefold in fat. In *Clarius* and *Serranochromis* the proportion of the total residues present as the sulphate increased from 4% to 16% after the first spray to 61% to 89% after the last spray. In *Schilbe* no Endosulphan sulphate was present after spray one and even after the final spray, only 36% to 39% was found. This may indicate a lower rate of breakdown in this species, but the number of samples taken was too small to draw any very firm conclusions. Furthermore, while the total amount of Endosulphan in the fat of *Clarius* and *Serranochromis* decreased by amounts up to elevenfold over the spray season, that in the fat of *Schilbe* increased ninefold. This increase is associated with a corresponding increase in proportion of total fat in this species and it appears that the concentration of residues in the fat of all the species studied is almost linearly related to the size of the fat reserves.

From the figures in Table 3 it is clear that uptake of the insecticide by fish from the water must be rapid. The concentration factor between the levels in water and fish 2,5 days after the first spray is approximately 2×10^4. It also seems that in *Serranochromis* and *Clarius* at least breakdown and excretion must also be rapid, since at the end of the spray season the levels were lower than at the beginning.

TABLE 3

Endosulphan residues in fish from Shorobe lagoon, June-September 1975

	Viscera	*Muscle*	*Fat*
Clarius gariepinus			
Pre-spray I (June)	n.d.	n.d.	n.d.
Post-spray I (June)	0,02 (5%)	0,02 (4%)	1,1
Post-spray V (Sept.)	0,01 (88%)	0,01	0,1
Serranochromis thumbergi			
Pre-spray I (June)	no data	n.d.	n.d.
Post-spray I (June)	0,22 (16%)	0,02 (15%)	2,4
Post-spray V (Sept.)	0,11 (89%)	0,01 (61%)	2,6
Schilbe mystus			
Pre-spray I (June)	no data	n.d.	n.d.
Post-spray I (June)	0,01 (0%)	0,01	0,2
Post-spray V (Sept.)	0,19 (36%)	0,02 (39%)	1,8

NOTE: n.d. = not detectable. All figures in parts per million.

Future work

During 1976 regular sampling of both fish and plankton commenced in two lagoons close to Maun. During the spraying season, one of these will be sprayed at the same intervals and with the same concentration of insecticide as the main spray block, while the second will be used as a control site. Seine-netting will continue on a monthly basis and during the spray season samples will be taken at the same time as spray application. In addition, gill net samples will be taken from time to time to obtain larger fish for growth and ageing measurements. Further tests will be carried out using caged fish in sprayed and unsprayed water to establish whether the increased rate of application is likely to have immediate toxic effects.

Work on freshwater invertebrates will concentrate on plankton of the lagoons mentioned above, since it would seem probable that there is more immediate and direct contact between the insecticide and this part of the fauna than is the case with bottom-living fauna. It is also hoped to be able to carry out some cage studies similar to those using fish, but substituting such larger invertebrates as snails, freshwater shrimps and larvae of Odonata and Ephemeroptera.

Conclusions

The data presented here, which essentially represents those obtained during the first four months of the project, certainly do not permit us to draw any very firm conclusions as to the effects of this insecticide on the aquatic ecosystem as a whole. What they do suggest, at least as far as fish are concerned, is that there is unlikely to be immediate mortality as a result of spraying at the very low rates of application used during the 1975 trials. No firm data is available for aquatic invertebrates, but since toxicity tests in the laboratory have shown that they are, in general, less sensitive to Endosulphan than fish, it seems possible that they will also be unaffected. Work on sub-lethal effects on fish will be undertaken on any effects on breeding, growth and feeding habits of at least the more abundant species. During the 1976 spraying season it is planned to increase the application rate of the insecticide to 12 g/ha for the first

two spray cycles. This should provide an excellent opportunity to study any immediate effects at two different concentrations and to observe any longer-term effects resulting from the higher concentration rate.

REFERENCES

Cope, O. B. 1961. "Effects of DDT spraying for spruce budworm on fish in the Yellowstone River system." *Trans. Am. Fish. Soc.*, 90:239-251.

Gorbach, S. et al. 1971. "Residue analysis and biotests in rice fields of East Java treated with Thiodan." *Bull. Environ. Contam. Toxicol*, 6:193-199.

Holsing, G. C. 1964. Unpublished report. *Food Machinery Corporation, Niagara Chemical Division.* Quoted in: Maier-Bode, H. 1968.

Hunt, E. G. and Bischoff, A. L. 1960. "Inimical effects on wildlife of periodic DDD applications to Clear Lake." *Calif. Fish Game*, 46:91-106.

Maier-Bode, H. 1968. "Properties, effects, residues and analytics of the insecticide Endosulphan." *Residue Revs.*, 22:1-44.

President's Scientific Advisory Committee. 1963. *Use of Pesticides.* (Washington DC. US Government Printing Office).

Tarzwell, C. M. 1963. In: *Pesticides: Their use and Effect.* p 30. Ed. G. A. Swanson, New York.

Woodwell, C. M. et al. 1967. "DDT residues in an East Coast estuary: a case of biological concentration of a persistent insecticide." *Science*, 156:821-824.

General Discussion

The panel discussed papers on fish, crocodile, tsetse fly and the eradication of tsetse fly in the Okavango Delta. The apparent low standing fish stocks and means to increase productivity were discussed at length. **Mr Fox** had stated that he sees the permanent papyrus swamps as a major limiting factor in fish productivity as the swamps are responsible for the low nutrient value of the Okavango water. **Mr Thompson** pointed out that the removal of the swamps would drastically decrease the biological productivity of the whole system to nobody's benefit. **Mr Fox** clarified his statement by saying that he did not advocate any modification to the system to increase fish productivity, but wanted better fishing methods utilising existing stocks. To the question whether fish farming should be attempted in the Delta (**Mr Reavell**), **Mr Fox** replied that currently there is little demand in Ngamiland and the marketing problems for exporting fish from the area are prohibitive. As a means to increase fish production the enrichment of the Okavango water, naturally and artificially, was suggested by several speakers, and examples were quoted where large fish productivity was apparently tied to enrichment through domestic or wild animals (Lake Ngami, Lake George, Kafue Flats, West Africa). **Mr Stark** pointed out that eutrophication causes considerable problems in the United States. **Mr Fox** replied that oxygen content of the water strongly influences the fish composition, e.g. Lake Ngami which seasonally has a very low oxygen content, supports during those times a very large population of catfish to the exclusion of other species; catfish is, however, a less desirable species. **Dr Passineau** pointed out that most speakers apparently view eutrophication only as a means to increase fish productivity but no reference had been made to the negative aspects of eutrophication in the Okavango Delta or elsewhere.

Dr Worthington commented on the function of stones in the stomachs of crocodiles, supposedly assisting in the balance, and observed cannibalism in other African territories. **Mr Graham** replied that he considered the offered explanation for stones in crocodiles stomachs as unconvincing. Okavango crocodiles have few stones in their stomachs due to the very fine substrata of the river, but do not seem to be handicapped in their movements, he thinks it is an unexplained phenomenon. Too few observations are recorded from the small sample of Okavango crocodiles.

The two papers on tsetse fly ecology and potential eradication of the fly caused considerable discussion and centred on the possibility of the eradication, the techniques to be applied and side effects on non-target species. **Dr Worthington** drew attention to the fact that a distinction between immediate and delayed effects of insecticides on aquatic invertebrates has to be made. He referred to a similar project currently being conducted in West Africa and stressed the importance of co-ordinating monitoring efforts with particular reference to the methodology of such projects to avoid meaningless and useless approaches. **Dr Russell-Smith** stated that the eradication of the fly employing aerial application of Endosuphan is probably technically feasible if current application rates (6 g/ha) will probably give little additional effects, considering the acute toxicity of Endosulphan to tsetse (50 times higher than for the house-fly). He also stressed again the preliminarity of their results regarding side-effects on non-target species. He pointed out that as far as it is presently known, Endosulphan is less damaging to the environment than other insecticides.

Mr Dincer referred to earlier remarks regarding the modification of the

hydrological system and stated that it is very dangerous to play around with the system considering the effects on flow pattern and sediment regime and should not be attempted. A big dam, e.g. in Angola, would drastically change the flow patterns, Botswana receiving a summer instead of a winter flood. This could be beneficial for fish breeding but the results might be no outflow at all.