EVALUATION OF LARVICIDES FOR THE CONTROL OF *SIMULIUM DAMNOSUM* S.L. (DIPTERA: SIMULIIDAE) IN WEST AFRICA

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ABSTRACT. The Onchocerciasis Control Program of the World Health Organization is carrying out an extensive screening program in a search for new larvicides to be used for control of *Simulium damnosum* s.l. Emphasis has been given to finding a pyrethroid and a carbamate to supplement the organophosphates currently in use. These chemicals with differing modes of action, together with *Bacillus thuringiensis* H-14, are being used in an attempt to cope with the development and spread of resistance to the organophosphates temephos and chlorphoxim.

INTRODUCTION

Temephos resistance in larvae of some cytospecies of the *Simulium damnosum* s.l. complex was first reported in the Onchocerciasis Control Program (OCP) area in West Africa in 1980 (Guillet et al.) and chlorphoxim resistance was first reported in 1982 (Kurtak et al.). These findings led to large-scale use of *Bacillus thuringiensis* H-14 (Kurtak 1986) and to an acceleration of a screening program in a search for possible alternative larvicides.

Considerations in selecting a candidate larvicide for testing include the following:

1. It must be active against all larval instars of *S. damnosum* s.l. Ideally, the concentration required to kill all of the larvae with a 10-min. exposure should not exceed 0.1 mg/liter (equivalent to temephos). Concentrations up to 0.3 mg/liter might be accepted in some circumstances but higher application rates cause serious logistical problems because of the limited capacities of the helicopters and fixed-wing aircraft used for spraying.

2. The distance that the larvicide remains nearly 100% effective downstream ("carry") should approach 20 km in large rivers.

3. Since the larvicide is added to rivers which serve as village water supplies, formulations with a rat oral toxicity greater than 250 mg/kg (LD50) are ruled out. In practice, this implies that dilute formulations of moderately toxic materials can be tested. Danger to the Program and aerial contractor staff handling the product must also be limited, especially since pilots work alone in remote locations.

4. The formulation, ideally, should have no acute or long-term toxic effects on fish even at considerable overdoses. Toxicity to non-target invertebrates should be minimal, but it is recognized that some reduction will occur. In principle, no important group of invertebrates should be eliminated, but shifts in proportions are considered to be tolerable.

5. The preferred formulation is an emulsifiable concentrate which has a lower specific gravity than water and forms a stable emulsion without agitation. Formulation has an important influence on performance, but the factors influencing effectiveness are not well understood. Wettable powders and flowable formulations, especially those which must be diluted with water, are more difficult and dangerous to mix, load and apply, and are generally avoided. The formulation should not degrade rapidly when stored as a concentrate in unprotected containers in a hot climate where the air temperature often reaches 40°C.

6. The applied larvicide should not be so stable as to lead to its accumulation in the food web.

7. Formulations with solvents that corrode the spraying equipment and the aircraft itself should be avoided.

Of the insecticides currently used or proposed for use in the program, only temephos comes close to meeting all of these criteria. Other than temephos, chlorphoxim (another organophosphate) and *B.t.* H-14 have already been used extensively. A pyrethroid (permethrin) and a carbamate (carbosulfan) have recently undergone large-scale operational trials in OCP and are entering into routine use.

This paper will briefly describe the screening methods and criteria for acceptance and then compare the new larvicides with those already available and comment on possible modalities for their use.

SCREENING METHODS AND CRITERIA FOR SELECTION[1]

To be introduced into the OCP screening program, a compound must first have demonstrated that it kills mosquito larvae at low concentra-

[1] This section deals with the screening of chemical compounds other than bacterial toxins and insect growth regulators which will be the subject of other reports.

tions. Mosquito trials are carried out by the WHO Pesticide Evaluation Scheme (WHOPES) which is described in World Health Organization (1982). The compounds must also meet the toxicological criteria mentioned in the introduction, as well as can be determined from the manufacturers data.

Susceptibility tests: As a first step in screening, the compound is subjected to a series of susceptibility tests to determine its cross-resistance status vis à vis larvae resistant to organophosphates. These tests are carried out according to the method of Mouchet et al. (1977). Mature larvae are exposed for 3 hours to technical grade compound mixed in oxygenated distilled water. The compound is added to the water as an alcoholic solution. There is no agitation. Temperature is held constant between 20 and 25°C and the mortality is read immediately at the end of the exposure. If there is significantly less mortality with organophosphate-resistant versus susceptible larvae, it is concluded that cross-resistance exists and the compound is not tested further. To date such tests have demonstrated cross-resistance with carbamates, and a negative correlation with pyrethroids (Kurtak et al. 1987a).

Trough test: If there is no evidence of cross-resistance, the formulated product is next tested in a field laboratory in a closed circuit trough system similar to that described in an unpublished OCP report.[2] In this system, a small electric pump circulates river water between a 60 liter plastic garbage can and a small trough. The trough discharges back to the garbage can over a narrow, shallow lip where the water velocity reaches that required by *S. damnosum* (about 1 m/sec). In the bottom of the lip is a removable metal plate. Field-collected larvae, when placed in the trough, migrate to the lip and attach to the metal plate. This plate is then transferred to the lip of another trough-bucket system where insecticide is circulating with the water. After a 10-minute exposure (length chosen to simulate a field application), the plate is transferred to a third untreated "holding" system where mortality is scored after 24 hours by counting the surviving larvae and comparing this number with the total exposed. All detached larvae are considered to have died. In the control plates subject to the same manipulations, detachment is less than 1%. In trough testing, the goal is to determine the minimum concentration which gives 100% or nearly 100% mortality. Insecticides that require more than 0.5 mg/liter/10 min to obtain this level of control are not tested further. The more active compounds are next tested in rivers.

River tests: If activity is sufficient, individual river applications are carried out to confirm the operational dose and observe the carry. These tests consist of applying the formulated product by spraying or pouring above a series of breeding sites (rapids) where trailing grass or other larval attachment sites have been checked and the densities of young (instar 1 to 5) and mature (instars 6 and 7) larvae have been estimated. Twenty-four hours after treatment the sites are examined again and the percentage reduction in larval numbers estimated. The initial dose used is the minimum which gave 100% effect in the troughs. If this result is not achieved in the field, river tests are continued until the minimum field dosing rate giving 100% is found. For a product to be considered for OCP operations this dosing rate should be no more than about 700 ml/cubic meter (m^3) of discharge (for a 25% EC formulation equivalent to 0.3 mg/l–10 min of AI or 0.5 mg/l–10 min for a 50% EC formulation). Compounds with dosing rates of 0.1 mg/l–10 min or less are much more attractive. If the product shows some promise, but the dose is high, the manufacturer will be asked to furnish more formulations.

The results of the carry observation are more difficult to interpret, since with any product carry will vary with the transport characteristics of the river. Among the characteristics influencing transport, discharge is the most important. An application of temephos at 0.1 mg/l–10 min in a river flowing at 2 m^3/sec in the dry season may only cover one rapids (a few hundred meters) while the same compound at 0.05 mg/l–10 min will clear 30 km or more of the same river in the rainy season at 200 m^3/second. In general, carry is considered "adequate" when results obtained are at least equivalent to the operational compounds, i.e., 2–5 km at 10 m^3/sec and 10–15 km at 100 m^3/second.

If activity and carry are adequate, several more river tests may be done to cover the range of turbidity and discharge to be encountered during operations. Later applications will be carried out with helicopter or fixed-wing aircraft equipped with standard OCP release equipment. Six or more river tests are often done. Several formulations may be tested in parallel to ensure that an optimum formulation has been found.

Non-target fauna: As soon as field effectiveness against *S. damnosum* s.l. is confirmed, evaluation of effects on the non-target invertebrates begins. Even before this, during the first river tests, a close watch is kept for drastic mortality of fish or Crustacea. Any evidence of this will cause the product to be dropped. Catastrophic effects almost never occur because of prescreen-

[2] Jamnback, H. 1982. Insecticide screening tests against *Simulium damnosum* larvae, Lama Kara, Togo. Unpublished OCP report.

ing based on manufacturer's data and literature. Lacking catastrophic effects, a detailed evaluation is carried out. The first step is a test against non-target insects in troughs parallel with standard insecticides [see Troubat (1981) for details of method]. Acute toxicity to fish and Crustacea is determined in aquaria. The effect of individual river applications is followed by surber sampling (before and after), drift net samples before, during and after the application, and observation of detachment of non-target insects in gutters (Lévêque et al. 1977).

Operational trial: If the short-term effects of individual treatments on the non-target fauna are acceptable, and all other criteria (compatibility with application equipment, etc.) are met, an operational trial is carried out. An entire river basin is treated weekly by aircraft. These treatments continue for several months, so that the effectiveness of the formulation both in controlling larvae and in reducing the number of biting *S. damnosum* s.l. females over a wide area can be evaluated. At the same time changes in the non-target fauna are monitored by a combination of the methods described above plus fish net catches before, during and after treatments. The monitoring continues for several months after the applications stop, to follow recolonization. Sediment samples are recovered along the river at the end of the trial and at various times after the treatments stop. Insecticide residues are extracted and analysed by appropriate methods (usually GLC).

All of the results from the aforementioned procedures are considered in making a decision as to if, and under what conditions, the product will be used operationally.

RESULTS AND DISCUSSION

As of December 1986, 18 organophosphate compounds, 2 organochlorine compounds, 10 carbamates, 17 pyrethroids and 6 miscellaneous categories have been screened. This includes a total of 115 formulations. The results are summarized in Appendix 1. Where several formulations have been tested, only the results with the best one are given. In general, it can be seen that most of the organophosphates have been rejected because of cross-resistance with strains resistant to temephos and/or chlorphoxim. Only one pyrethroid, permethrin, and one carbamate, carbosulfan, have been subjected to operational trials. Several other pyrethroids with similar characteristics may be suitable for operational trial, but have not been given high priority because of the probability of cross-resistance between pyrethroids, if resistance to permethrin were once selected.

In Tables 1 and 2, the newly-selected com-

Table 1. Performance of *Simulium* larvicides operational in the Onchocerciasis Control Program.

Compound	Class[1]	Formulation	Operational dose (mg AI/liter for 10 min)	Volume of formulation per m^3/sec (liters)	Influence of[2]		Carry[3] (km)		Effect on non-target invertebrates
					Algae	Turbidity	Low discharge	High discharge	
temephos	O-P	emulsifiable concentrate	0.05–0.1	0.15–0.30	0	+	1–3	50	acceptable for continuous use in all seasons
chlorophoxim	O-P	emulsifiable concentrate	0.05	0.15	0	0	1–3	15	acceptable for long-term use in wet season
carbosulfan	Carb	emulsifiable concentrate	0.05	0.12	0	0	3–6	10–15	acceptable for short-term use in wet season
permethrin	Pyr	emulsifiable concentrate	0.015	0.045	–	0	1–3	15	acceptable for short-term use in wet season
B.t. H-14 (Sandoz H-PD or Abbott 12AS)	bacterial toxin	suspension	1.2	0.72	–	–	1–2	10	acceptable for continuous use in all seasons

[1] For abbreviations see Appendix 1.
[2] 0 = neutral, + = increased efficacy, – = reduced efficacy.
[3] Distance below application point with 100% effect.
[4] 10 m^3/sec or less.
[5] 100 m^3/and above.

Table 2. Cost effectiveness and risk of selecting resistance of *Simulium* larvicides operational in the Onchocerciasis Control Program.

Compound	Relative cost per km of river treated[1]		Risk of selecting resistance
	Dry season (10 m^3/sec)	Wet season (500 m^3/sec)	
temephos	1.0	1.0	high (forest species) moderate (savannah species)
chlorophoxim	0.7	1.3	high (forest species) moderate (savannah species)
carbosulfan	0.9	2.3	moderate
permethrin	0.6	0.7	high
Bacillus thuringiensis H-14 (Sandoz HP-D or Abbott 12AS)	1.4	4.3	low

[1] temephos = 1.0.

pounds are compared with the existing operational compounds (temephos, chlorphoxim and *Bacillus thuringiensis* H-14 (Sandox HP-D formulation)). These tables will be commented on in some detail since they represent the knowledge gained by considerable practical experience.[3] A general review of control methods is given by Kurtak et al. (1987b).

Temephos has the best combination of low dosage rate, long carry (up to 50 km), mineral effect on non-target fauna and cost effectiveness. It has a very low mammalian toxicity and the formulation used does not damage application equipment or aircraft. The emulsifiable concentrate retains its efficacy after 3 or more years of storage under tropical conditions. Turbidity and high discharge rates in the rivers enhance its effectiveness to the extent that the dosage can be cut in half during the wet season. Unfortunately, resistance to it has developed in both forest and savannah species of the *S. damnosum* complex (Kurtak 1986, Kurtak et al. 1987b).

Chlorphoxim is as effective as temephos at the application point, but has a much inferior carry. It also has a more severe effect on non-target organisms and so is not normally used over long periods or when rivers are low. The emulsifiable concentrate formulation used is corrosive to spray equipment and aircraft and its storage life is not more than 2 years. In temephos-resistant populations, resistance to chlorphoxim develops in less than one year of weekly treatments. This resistance is not always stable in the absence of treatment and the product can be used for brief periods each year in some areas.

Bacillus thuringiensis H-14 is effective against both susceptible and resistant populations of *S. damnosum* s.l. It is not injurious to most non-target organisms. Although formulations have improved over the last 6 years, a high dosage rate is required (0.72 liter/m^3/sec of river discharge compared with temephos which requires 0.15 to 0.3 liter/m^3/second). Given the type of aircraft used in OCP, the use of *B.t.* H-14 is normally limited to rivers with a discharge rate below 100 m^3/second. In exceptional cases, it has been used, with considerable difficulty and added expense, in larger rivers to eliminate temephos-resistant larvae before other alternatives were available. The product is formulated as a more or less viscous suspension. Some formulations require dilution before application. Even those which do not must be applied as a coarse spray or dumped at high airspeeds to ensure good dispersel. Placement must be precise for effective control and carry is much inferior to that of temephos.[4] As a result, in large complex rapids, as much as 20 times more product is needed as compared to temephos and the cost is at least 4 times greater (Table 2). In the dry season, the increased cost of *B.t.* H-14 treatments is less, but still substantial, given the scale of OCP. Another disadvantage of *Bacillus thuringiensis* H-14 is that at the beginning of treatments, more weekly cycles are needed to achieve 100% control than with other products. There are consistently more small failures along treated rivers. Algae growing in stagnant pools between rapids in the dry season interfere with *B.t.* H-14 and make it necessary to increase the dosage. High turbidity during the wet season may also reduce effectiveness.

The potential for development of resistance

[3] In the height of the wet season, OCP aircraft apply about 8.5 tons of insecticide at up to 4,500 applications points on 15,000 km of river every week.

[4] Emulsifiable concentrates, especially of temephos, can be applied quite successfully through a simple pipe or dump system. Their placement is less critical, since there is a spreading effect and the emulsions form spontaneously.

to *B.t.* H-14 is thought to be low. Work with mosquitoes (World Health Organization 1986) showed only a low level of resistance after 60 generations. However, resistance to another strain of *Bacillus thuringiensis* has been detected in stored grain pests (McGaughey 1985). There remains considerable latitude for improving the effectiveness of the product through augmenting active toxin content and improving formulation.

Permethrin is effective against *S. damnosum* s.l. larvae at dosage rates 1/6 to 1/3 that of temephos. Permethrin is available as an emulsifiable concentrate that posts no problems so far as its stability in storage, its dispersal in river waters, or its corrosive effect on equipment are concerned. Unfortunately, the carry is less than for temephos, not exceeding 15 km under ideal conditions for any of the many formulations that have been tested (unpublished OCP data). Nonetheless, due to its effectiveness at low concentrations, the cost/km of river treated is only 60 to 70% that of temephos. As is the case with *B.t.* H-14, high concentrations of algae, such as may be found in nearly stagnant rivers during the dry season, can reduce the effectiveness of permethrin to almost zero.

Permethrin is somewhat more effective against a organophosphate-resistant population of *S. damnosum* than against a susceptible population. There is also some evidence that permethrin accelerates the reversion of chlorphoxim resistance. The operational usefulness of this phenomenon is being explored (Kurtak et al. 1987a).

Permethrin causes the most severe reduction in non-target invertebrates of any of the larvicides in operational use. This reduction persists as long as the treatments are continued. However, after treatment stops, recovery to pretreatment levels occurs within a few months. Permethrin is only used for short periods at high river discharge to eliminate organophosphate resistant populations.

Many insects readily develop resistance to pyrethroids with widespread cross-resistance to other pyrethroids (World Health Organization 1976). As pyrethroids are used to control cotton pests along the banks of some rivers in the OCP area, there is the possibility that some preselection has already occurred due to runoff. Even in areas where no *Simulium* larviciding has been carried out, seasonal changes in pyrethroid susceptibility have been recorded (OCP unpublished data). These may be related to agricultural use.

Carbosulfan, in its present formulation, requires the same dosage rate as chlorphoxim, and has the same limited carry of about 15 km below the treatment point under optimal conditions. The insecticide formulated as 250 g AI/liter EC is not corrosive to equipment. Its storage life under tropical conditions is at least 18 months.

Carbosulfan is less injurious to non-target organisms than permethrin, but more toxic than temephos or chlorphoxim. Its toxicity becomes more pronounced at river discharge rates below 75 m^3/sec. Below 25 m^3/sec there is a danger that fish will be traumatized (OCP unpublished data). Therefore, this product can only be used at high river discharges and for limited periods of time.

There is also a risk of resistance developing to carbamates, including carbosulfan, which could lead to cross-resistance to organophosphates but not to pyrethroids according to Hemingway and Lines (1985).

The pattern of use of these and other larvicides in future OCP operations will depend on the extent and character of resistance that develops in *S. damnosum* s.l. populations and on a further analysis of their effects on non-target fauna. The present strategy is to use *B.t.* H-14 during the dry season when the rivers are low because it is nearly as effective and much less injurious to non-target fauna than the other operational insecticides and also because it is less likely to provoke the development of resistance. These advantages compensate the moderate increase in cost. As river discharges increase, organophosphates, carbamates and pyrethroids will be used in a sequence determined by the susceptibility of the populations involved. Temephos will remain the product of choice during the rainy season when rivers are high and where there is no resistance. It is hoped that dry-season alternation with *B.t.* H-14 will retard the development of resistance to temephos.

Where resistance to temephos occurs, chlorphoxim will be used when there is no cross-resistance. An alternation between chlorphoxim and permethrin might be envisaged if the "negative correlation" proves to be operationally useful. If not, carbosulfan might be chosen over permethrin in spite of its high cost because it is not as injurious to non-target fauna and less likely to provoke the development of resistance as compared to permethrin.

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REFERENCES CITED

Guillet, P., Escaffre, M. Ouédraogo and D. Quilévéré. 1980. Mise en évidence d'une résistance au téméphos dans le complexe *Simulium damnosum* (*S. sanctipauli* et *S. soubrense*) en Côte d'Ivoire. (Zone du Programme de Lutte contre l'Onchocercose dans la Région du Bassin de la Volta). Cah. O.R.S.T.O.M. Ser. Entomol. Med. Parasitol. 17:291–299.

Hemingway, J. and J. D. Lines. 1985. Pesticide sequence and resistance avoidance. WHO unpublished document VBC/ECV/EC 85.31, 6 pp.

Kurtak, D. 1986. Insecticide resistance in the Onchocerciasis Control Programme. Parasitol. Today 2:19–20.

Kurtak, D., M. Ouédraogo, M. Ocran, T. Barro and P. Guillet. 1982. Preliminary note on the appearance in Ivory Coast of resistance to chlorphoxim in *Simulium soubrense/sanctipauli* larvae already resistant to temphos (Abate (R)). WHO unpublished document WHO/VBC/82. 850.

Kurtak, D., R. Meyer, M. Ocran, M. Ouédraogo, P. Renaud, R. Sawadogo and T. Barro. 1987a. The potential use of negative correlation between organophosphate resistance and pyrethroid susceptibility in managing resistance in *Simulium damnosum* s.l. (Diptera: Simuliidae) in the Onchocerciasis Control Programme. Med. Vet. Entomol. 1 (in press).

Kurtak, D., J. Grunewald and D. A. T. Baldry. 1987b. Chemical control of *Simulium* vectors of onchocerciasis in Africa. *In:* K. C. Kim and R. W. Merritt (eds.), Black flies: Ecology, population management and annotated world list. Pennsylvania State Univ. Press (in press).

Lévêque, C. M. Odei and M. Pugh-Thomas. 1977. The Onchocerciasis Control Programme and the monitoring of its effect on the riverine biology of the Volta River Basin, pp. 133–143. *In:* F. M. Perring and K. Mellanby (eds.) Ecological effects of pesticides. Linn. Soc. Symp. Ser. No. 5. London.

Mc Gaughey, W. H. 1985. Insect resistance to the biological insecticide *Bacillus thuringiensis*. Science 229:193–195.

Mouchet, J., G. Quelennec, D. Berl, Y. Séchan and S. Grébaut. 1977. Méthodologie pour tester la sensibilité aux insecticides des larves de *Simulium damnosum* s.l. Cah. O.R.S.T.O.M. Ser. Entomol. Med. Parasitol. 15:55–56.

Troubat, J. J. 1981. Dispositif à gouttières multiples destiné à tester *in situ* la toxicité des insecticides vis à vis des invertébrés benthiques. Rev. Hydrobiol. Trop. 14:149–152.

World Health Organization. 1976. Resistance of vectors and reservoirs of disease to pesticides. W.H.O. Tech. Rep. 585. 88 pp.

World Health Organization. 1982. Meeting of the directors of WHO Collaborating Centers on the evaluation and testing of new insecticides. WHO published document WHO/VBC/82.846. Rev. 1. 40 pp.

World Health Organization. 1986. Resistance of vectors and reservoirs of disease to pesticides. W.H.O. Tech. Rep. 737. 87 pp.

APPENDIX 1.

Compounds tested as *Simulium damnosum* larvicides in the Onchocerciasis Program since the beginning of accelerated screening in 1982.

			Results					
Compound[1]	Class[2]	Formulation[3]	Cross-resistance	Trough test[4]	River trial[5]	Effect on non-target fauna	Operational trial	Remarks
azamethiphos (Ciba-Geigy)	O-P	EC 10%	no	acceptable (0.2 to 0.3)	insufficient activity (0.3/3–6/10–20)	acceptable	none	poor storage life, 10% max. conc.
bromophos (Celamerck)	O-P	tech AI	yes	none	none	unknown	none	–
OMS 3036 CME 16002 (Celamerck)	O-P	EC 48%	no	acceptable (0.3)	in progress	in progress	none	–
chlorfenvinphos (Shell)	O-P	tech AI	yes	none	none	unknown	none	–
chlorphoxim (Bayer)	O-P	EC 20%	no[6]	acceptable (0.05)	acceptable (0.05/2–3/2) (0.05/2–8/35)	acceptable	1977	"improved" formulations
chlorpyrifosmethyl (Dow)	O-P	tech AI	yes	–	none	unknown	none	–
dichlorvos (Ciba-Geigy)	O-P	EC 50%	no	insufficient activity (0.53 = 98%)	none	unknown	none	–
etrimphos (Sandoz)	O-P	tech AI	yes	–	none	unknown	none	–
fenchlorvos (Dow)	O-P	tech AI	yes	–	none	unknown	none	–
fenthion (Bayer)	O-P	tech AI	yes	–	none	unknown	none	–
iodenphos (Ciba-Geigy)	O-P	tech AI	yes		none	unknown	none	–
pirimiphosmethyl (ICI)	O-P	tech AI	yes	–	none	unknown	none	–
propetamphos (Sandoz)	O-P	tech AI	yes	–	none	unknown	none	–
temephos (Phytagri)	O-P	EC 20%	N.A.	acceptable (0.2)	acceptable (0.1/6.5/7)	acceptable	successful	alternative supplier
temephos sulfone (Cyanamid)	O-P	tech	yes	none	none	unknown	none	–
temephos sulfoxide (Cyanamid)	O-P	tech AI	yes	none	none	unknown	none	–
tetrachlorvinphos (Shell)	O-P	tech AI	yes	none	none	unknown	none	–
trichlorphon (Bayer)	O-P	tech AI	yes	none	none	unknown	none	–
cartap (Takeda)	Carb	WSP 50%	no	insufficient activity (1.0 = 50%)	none	unknown	none	–
carbosulfan (FMC)	Carb	EC 25%	no	acceptable (0.05)	acceptable (0.05/10–15690) (0.05/8–9/17)	acceptable for short periods	successful	formulation under development

APPENDIX 1.—*Continued*

Compound[1]	Class[2]	Formulation[3]	Results					
			Cross-resistance	Trough test[4]	River trial[5]	Effect on non-target fauna	Operational trial	Remarks
ethiofencarb (Bayer)	Carb	EC 50%	no	insufficient activity (2.0 = 93%)	none	unknown	none	–
macbal (Hodogaya)	Carb	EC 20%	no	insufficient activity (3.0 = 98%)	none	unknown	none	–
methiocarb (Bayer)	Carb	F 50%	no	acceptable (0.5)	acceptable (0.35/6/4)	unknown	none	formulation unsuitable for operational use
methiocarb (Bayer)	Carb	EC 10%	no	acceptable (0.5)	acceptable (0.3/3.5/2) but formulation too dilute	unknown	none, dosage almost 2 liters/m^3	impossible to increase AI content
metolcarb (Sumitomo)	Carb	EC 30%	no	insufficient activity (2.0 = 75%)	none	unknown	none	–
pirimicarb (ICI)	Carb	EC 5%	no	insufficient activity (0.6 = 0%)	none	unknown	none	–
propoxur (Bayer)	Carb	EC 2%	no	insufficient activity (1.3 = 83%)	none	unknown	none	–
thiodicarb (Union Carbide)	Carb	F 37.5%	no	insufficient activity (1.1 = 83%)	none	unknown	none	–
xylylcarb (Sumitomo)	Carb	EC 30%	no	insufficient activity (0.7 = 93%)	–	unknown	–	–
DDT (Ligtermoet Chemical B.V)	O-C	EC 25%	no	acceptable (0.3)	acceptable (0.2/3/1.5)	residues pose serious problems	used sucessfully for many years before OCP	emergency use only authorized
methoxychlor (Nordisk)	O-C	EC 30%	no	acceptable (0.5)	insufficient activity (0.5 = 90%/0.5/2)	unknown	–	–
alphamethrin (Shell, FMC, ICI)	Pyr	EC 10%	no	acceptable (0.01)	acceptable (0.010/3/4)	more toxic than permethrin	none	–

cyfluthrin (Bayer)	Pyr	EC 5%	no	acceptable (0.015)	none	similar to permethrin	none	no advantage over permethrin
cyhalothrin (ICI)	Pyr	EC 10%	no	acceptable (0.025)	acceptable (0.025/ 7.8/4)	less than permethrin but kills Crustacea	none	too toxic to Crustacea
cypermethrin (Shell)	Pyr	EC 40%	no	acceptable (0.006)	acceptable (about 0.01)	very severe, especially Crustacea	none	more toxic to non-target fauna than to *Simulium*
cyphenothrin (Sumitomo)	Pyr	EC 5%	no	acceptable (0.005)	acceptable (0.01/1/ 11)	similar to permethrin	none	no advantage over permethrin
cypothrin (Cyanamid)	Pyr	EC 20%	no	acceptable (0.10)	insufficient activity	unknown	none	–
deltamethrin (Roussel-Uclaf)	Pyr	EC 1%	no	acceptable (0.0005)	acceptable (0.002/ 4/12)	severe mortality to Crustacea	none	effective, but too toxic for non-target fauna
esfenvalerate (Sumitomo)	Pyr	EC 2.5% F 5%	no	insufficient activity (1.0 to 2.0)	none	unknown	none	–
ethoproxyfen (Zoecon/Mitsui Toatsu)	Pyr	EC 60%	no	acceptable (0.1)	acceptable (0.2/3/ 1)	similar to permethrin	none	high dosage rate required
fenfluthrin (Bayer)	Pyr	EC 20%	no	acceptable (0.01)	acceptable (0.015/ 2.5/1.8)	similar to permethrin	none	no advantage over permethrin
flucythrinate (Cyanamid)	Pyr	EC 20%	no	acceptable (over 0.13)	none	probably severe	none	high mammalian toxicity
fluvalinate (FMC)	Pyr	EC 25% F 24%	no	acceptable (0.1 to 0.5)	insufficient activity (0.48 = 99% at 150m)	moderate at 0.25	none	dosage rate too high
OMS 3021 (ICI PP 321)	Pyr	EC 5%	no	acceptable (0.02)	acceptable (0.01 = 99%)	similar to permethrin	none	no advantage over permethrin
permethrin (Shell, Wellcome ICI, FMC)	Pyr	EC 20%	no	acceptable (0.010 to 0.015)	acceptable (0.015/ 15/86)	roughly 70% reduction, 80–90% of Emphemeroptera	1984 in operational use	–
Pynaminforte (Sumitomo)	Pyr	EC 5%	no	acceptable (0.02 to 0.1)	in progress	moderate at 0.02	none	–
neo-Pynaminforte (Sumitomo)	Pyr	EC 5%	no	acceptable (0.05 to 0.1)	in progress	unknown	none	–
Talstar® FMC 54800 (OMS 3024)	Pyr	EC 10	no	acceptable (0.01)	in progress	similar to permethrin	none	–

APPENDIX 1.—*Continued*

Compound[1]	Class[2]	Formulation[3]	Results: Cross-resistance	Results: Trough test[4]	Results: River trial[5]	Results: Effect on non-target fauna	Results: Operational trial	Remarks
avermectin (Merck, Sharpe and Dohme)	lactone	EC 1	no	acceptable (0.03)	none	unknown	none	mammalian toxicity too high
Bensultap (Takeda)	*Nereis* toxin	WP 50% EC 25%	no	insufficient activity (0.5 to 3.0+)	none	unknown	none	–
evisect (Sandoz)	*Nereis* toxin	WSP 25%	no	insufficient activity (over 6.0)	none	unknown	none	–
octyl propargyl sulfite (Uni-Royal)	sulfite	EC 90%	no	insufficient activity (0.5 = 50%)	none	unknown	none	–
BTS 49178, pure Zisomer OMS 3027 (FBC)	hydrazone	F	no	insufficient activity (1.2)	none	unknown	none	–
BTS 49178, Z + E isomers OMS 3028 (FBC)	hydrazone	F	no	insufficient activity (1.2)	none	unknown	none	–

[1] Common name, WHO code, or manufacturer's code. Manufacturer in parentheses.
[2] O-P = organophosphate, Carb = carbamate, Pyr = pyrethroid, O-C = organochlorine.
[3] EC = emulsifiable concentrate, F = flowable, WDP = water dispersable powder, WSP = water soluble powder.
[4] In parentheses = LC 100 in mg/liter/10 min.
[5] In parentheses = operational dose in mg/liter/10 min followed by carry in km followed by river discharge in m^3/sec.
[6] Multiple resistance develops rapidly.