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REVIEW

Criteria for the selection of larvicides by the Onchocerciasis Control Programme in West Africa

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One of the weekly decisions the Onchocerciasis Control Programme has to make, in its operations in 11 west African countries, is the selection of one insecticide out of the six used that is most appropriate to the river stretches to be treated. This decision depends on several criteria, linked not only to the compounds themselves but also the hydrological conditions and blackfly populations involved. Given the great number of breeding sites (gites) to be treated, in 23 000 km of rivers at the height of the rainy season, this paper identifies the parameters needed to facilitate the choice of insecticide and to optimize the larviciding in terms of cost effectiveness, management of resistance and minimizing the environmental impact.

The Onchocerciasis Control Programme in West Africa (OCP), which was launched in 1974, is executed by the World Health Organization. There are 11 participating countries in the Programme area, which covers more than a million km^2. The Programme's objective is to control blinding onchocerciasis caused by savanna strains of *Onchocerca volvulus* (Zimmerman *et al.*, 1992) transmitted by the *Simulium damnosum* complex, particularly the savanna vectors *S. sirbanum* and *S. damnosum* s.s. Despite the introduction of ivermectin, a microfilaricide which controls the ocular morbidity (Dadzie *et al.*, 1990) and in the absence of a macrofilaricide, vector control remains OCP's method of choice to bring the transmission of the parasite to an end. The objective of the vector control strategy is to arrest transmission of *O. volvulus* by eliminating vector populations for the duration of the life span of the adult worm in the human host (WHO, 1968), at present calculated to be about 14 years (Plaisier *et al.*, 1991). Onchocerciasis is thus no longer a public health problem in the original Programme area, where control, that has only involved the vectors, has been maintained for more than 14 years (WHO, 1992).

The vector control operations consist of treating breeding sites (gites), where the larval

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stages of *S. damnosum* s.l. develop, with insecticides. As development of the aquatic stage takes about a week from egg to pupa, the insecticide is applied weekly. As there are a large number of breeding sites (over 23 000 km of river are treated each rainy season), some of which are inaccessible on the ground, the larvicides have always been applied as aerial sprays. Temephos, an organophosphorous compound and the only insecticide used for the first 5 years of the Programme, was selected because of its efficiency, its carry (the distance over which it remains effective), its lack of impact on non-target fauna, and its acceptable cost. After resistance of *S. damnosum* to temephos and phoxim (another organophosphate) was detected (Guillet *et al.*, 1980), the Programme adopted a strategy of rotational use of insecticides (which, if possible, came from different chemical groups and had different modes of action) to slow down and suppress the appearance of new cases of resistance (Guillet *et al.*, 1990; Kurtack, 1990). This rotational use of insecticides has, to date, been so effective that there is now very little resistance left to the organophosphates in use and the susceptibility of the *Simulium* population to the other compounds remains unchanged.

The vector control operations staff must decide each week which insecticide to use on which stretch of river. The decision whether or not to include a river, tributary or stretch in the aerial larviciding depends on: (1) the results of a weekly entomological evaluation of the efficiency of earlier treatment on the aquatic stages (involving a search for larvae and pupae in rivers) and adults (involving capture and dissection); (2) factors such as fly migrations; (3) the vectorial capacity of the species involved; (4) the level of onchocerciasis endemicity in the area; and (5) the treatment coverage with ivermectin. When larviciding operations are foreseen, the second step consists of selecting, for each river, the appropriate compound to be used. Although many parameters used in the overall decision-making process are difficult to codify and subject to mathematical analysis, the criteria for selection of an insecticide are simpler and therefore easier to quantify for rational computer analysis. These criteria are discussed and reviewed here to facilitate the work of those in charge of the vector control operations.

CRITERIA FOR THE SELECTION OF INSECTICIDES

Efficiency and Potential Resistance

Six insecticides are presently used by OCP. Five of them are chemical insecticides formulated as emulsifiable concentrates and the sixth is a liquid concentrate of a biological insecticide. Of these, two organophosphates, temephos and pyraclofos, are considered to be the most effective larvicides; their required operational doses are low and their carry may reach over 50 km when the river discharge is high (around 300 m^3/s). Temephos, however, should be used with caution in areas where some species of the *S. damnosum* complex have retained low susceptibility to it since 1980, bearing in mind the risk of cross-resistance with other organophosphates (Kurtak *et al.*, 1987). Pyraclofos is therefore preferentially used at the beginning of the rainy season, when discharges are increasing and the breeding sites are being recolonized. Although permethrin, a synthetic pyrethroid, has a low carry compared with temephos and pyraclofos, its operational dose is very low and no case of resistance to it has been detected by the OCP. There seems negligible risk of such resistance developing; it took more than 3 years of consecutive weekly treatment with permethrin on a 30-km river stretch in Cameroon before a decrease in the sensitivity of the flies to this product could be detected and this phenomenon was found to be reversible (Hougard *et al.*, 1992). Carbosulfan is a carbamate with almost the same carry as permethrin but with a higher operational dose. There are no restrictions on its use because of problems with resistance; it has been recently introduced into the Programme and the current policy of insecticide rotation should prevent any serious resistance developing. Use of the spore-forming bacterium *Bacillus thuringiensis* serotype H-14 (Bt), as a biological insecticide, has shown low cost-efficiency, both in terms of dose and carry. However, its use is justified because it has no effect on non-target organisms and, again, because there is little chance of resistance to it developing (Hougard and Back, 1992).

Environmental Toxicity

The insecticides used in the Programme are continually evaluated by an independent ecological group (Paugy, 1991), given the fact that a larvicide for *Simulium* control, no matter how effective it is, would not be accepted for use by OCP if it had short-, intermediate- or long-term deleterious effects on the environment, particularly on fish. Temephos and Bt are considered harmless to the environment and are used freely. Pyraclofos may, in cases of accidental overdose, show some toxicity against non-target fauna, particularly to fish, and it is recommended that the use of pyraclofos be restricted to discharges above 15 m^3/s. Permethrin and carbosulfan should also be used with caution, only when the discharge stays above 70 m^3/s, and no more than six times a year on any stretch of river. In general, all chemical insecticides should be used in a manner which avoids the possibility of an overdose likely to harm the environment. The Programme has established a satellite transmission network to record water discharges and permit rapid management of hydrological data for the safe treatment of rivers (Servat and Lapetite, 1990).

Cost of Application

Cost effectiveness is a key factor in the selection of a compound. To make a correct estimate of this, OCP requires that not only those variables related to the insecticide itself be considered (operational dose, carry, cost of formulation) but also those related to its transport and application (fuel and maintenance for vehicles, staff, maintenance and protection of depots, kerosene, flight hours). The discharge of the river must also be taken into account when assessing the treatment cost, since it influences the amount of insecticide used, its carry, its operational dose (in the case of temephos), the frequency at which depots need replenishing and the number of flight hours. Each parameter can be evaluated accurately enough to allow the cost effectiveness for each kilometre of river treated to be assessed as an index for each range of discharges and each insecticide (see Table). This allows the comparative costs of applications of different insecticides to one river to be calculated and is also an important criterion for establishing priority among the six insecticides in use. Experience has shown that U.S.$45–50/km of river treated may be considered the maximum cost of treatment within the budgetary constraints of the Programme.

The Spraying System

Treatment helicopters are equipped with a spraying system that allows for dosing of insecticides with an accuracy of 10 cm^3. However, below a given quantity (which depends on the formulation of the product), it is difficult for the pilot to apply the correct amount of the insecticide to a breeding site, especially when it is impossible to fly at low altitude because of the vegetation. In particular, accurate treatment of discharges below 1 m^3/s with those compounds that have a low operational dose (temephos and phoxim) becomes hazardous. This constraint does not apply to Bt, which, due to its low solubility, is never applied in values less than 1 litre, even to very low discharges.

Hydrological Characteristics of the Rivers

In the majority of cases, the hydrological characteristics of the rivers do not pose any special problems if the selection criteria listed above are adhered to. However, the choice of insecticides for use on rivers that have a particularly high discharge over a long period of time may be limited by cost effectiveness, in particular when the ecological constraints on permethrin or carbosulfan use (i.e. not more than six cycles/year on any river stretch) are observed. Consequently, the hydrological characteristics of large rivers, such as the Niger at Bamako (where the discharge varies from 70 to 3000 m^3/s) and some rivers in the forest zone of Sierra Leone (e.g. the Rockel)

TABLE

*The cost-efficiency index (in U.S.$) for each kilometre of treated river**

	Discharge (m^3/s)								
Larvicide	*0–5*	*5–10*	*10–15*	*15–50*	*50–100*	*100–150*	*150–200*	*200–250*	*250–300*
Temephos	7	8	8	11	16	22	27	31	36
Pyraclofos	N.D.	N.D.	9	12	19	26	33	38	43
Phoxim	13	17	22	34	**54**	84	97	122	147
Permethrin	N.D.	N.D.	N.D.	12	14	16	20	21	24
Carbosulfan	N.D.	13	14	22	32	43	**57**	65	77
Bt	27	36	43	**71**	114	N.D.	N.D.	N.D.	N.D.

	Discharge (m^3/s)								
Larvicide	*300–350*	*350–400*	*400–450*	*450–500*	*500–600*	*600–700*	*700–800*	*800–900*	*900–1000*
Temephos	39	45	48	**49**	**54**	N.D.	N.D.	N.D.	N.D.
Pyraclofos	**50**	50	62	66	N.D.	N.D.	N.D.	N.D.	N.D.
Phoxim	172	198	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
Permethrin	27	27	30	32	36	41	47	**52**	52
Carbosulfan	90	94	105	116	N.D.	N.D.	N.D.	N.D.	N.D.
Bt	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.

*The index is calculated using the equation $\{[100/P] \times D \times Q \times (F+X)]+Ty\}/100$, where P is the carry, $(100/P)$ is the number of applications or 'drops' needed to treat 100 km of river, D is the mid-point of the discharge range (m^3/s), Q is the quantity of formulation to be dropped per m^3/s discharge (litres), F is the cost of the larvicide (U.S.$/litre), X is the cost of transporting a litre of the larvicide close to the river (about U.S.$0·06), T is the time it takes to treat 100 km of river—including refuelling at the depot (min), and y is the total cost of the helicopter flight—including maintenance, kerosene and pilot salary (U.S.$13·57/min). Emboldened values exceed the budgetary constraints of the Programme.

N.D., Not determined; Bt, *Bacillus thuringiensis* H-14.

with discharges greater than 300 m^3/s for many months each year, have to be carefully considered.

OPERATIONAL USE OF INSECTICIDES

After considering all the various constraints, it has been possible to prepare a scheme for the use of insecticides according to the discharge of the river to be treated (Fig. 1). Below 1 m^3/s, only Bt should be used, and above 450 m^3/s only permethrin is appropriate. Between 1 and 15 m^3/s, temephos, phoxim or Bt can be used. At 15–70 m^3/s, the three organophosphorous compounds should be used; Bt becomes too expensive for use under these conditions. Between 70 and 150 m^3/s there is more choice; temephos, pyraclofos, permethrin and carbosulfan are all usable. Carbosulfan becomes too expensive to use at 150–300 m^3/s and between 300 and 450 m^3/s the cost-efficiency index reduces the choice to only temephos or permethrin. This scheme can be applied to most of the rivers in West Africa under larviciding once the characteristics of each river (hydrological conditions, configuration of breeding sites, and potential for insecticide resistance) are known. It does, however, need to be adapted at certain sites which have unusual features. Two such sites are outlined below.

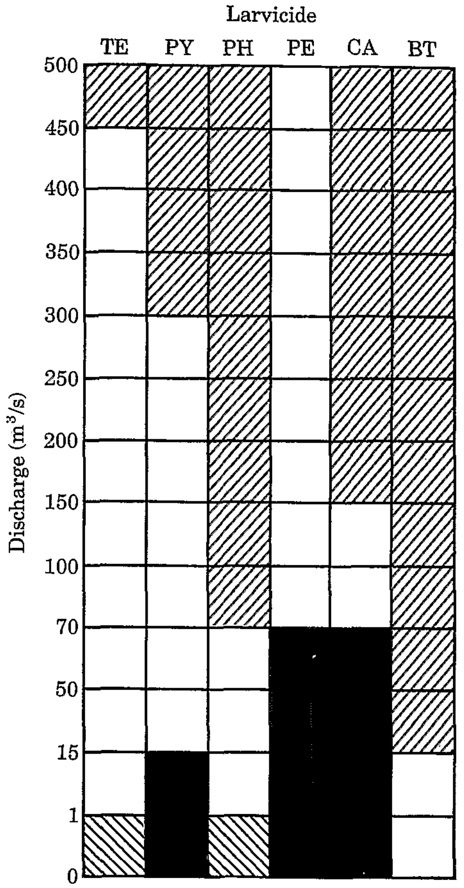

Fig. 1. The generally preferred insecticide(s) (□) for different discharges. Low cost efficiency (▨), potential environmental damage (■), or lack of accuracy in application (▧) make each insecticide unusable under certain conditions. TE, Temephos; PY, pyraclofos; PH, phoxim; PE, permethrin; CA, carbosulfan; BT, *Bacillus thuringiensis* H-14.

The Marahoué River in Côte d'Ivoire

The Marahoué river begins in the north of Côte d'Ivoire, in the area of Boundiali, and ends in the white Bandama near which, in 1980, the first cases of temephos resistance in species of the *S. damnosum* complex were detected. Although the level of susceptibility to this compound is now acceptable and even though the risk of cross-resistance remains, the two other organophosphates are used instead of temephos (Fig. 2). This ban on temephos use could be a handicap at discharges greater than 300 m^3/s because permethrin would be the only usable compound. In reality, the problem does not arise, since the discharge on the Marahoué seldom exceeds 300 m^3/s except during the temporary flood and this never lasts more than 1 week. In any case, since the Marahoué river has recently been selected for an evaluation of the impact of carbosulfan on non-target organisms, no permethrin will be used on it until this assessment is complete.

The Niger River near Bamako

The Niger river begins in Guinea, passes through Mali and Niger, and ends on the Nigerian coast. Around Bamako there is a stretch of tens of kilometres in which *Simulium* breed, although there are no breeding sites further up- or down-stream. Neither phoxim nor Bt can be used on this stretch as the discharge is seldom below 70 m^3/s (Fig. 2). Temephos is not used because resistance to it was detected in the area in 1988. Carbosulfan is seldom applied because the discharge is only suitable for its use (70–150 m^3/s) for about 10 weeks each year. Pyraclofos is more frequently used, in preference to other products that could have been chosen for the discharges involved. As the discharge is about 300 m^3/s for about two thirds of the year, permethrin is widely used. As resistance to organophosphorous compounds decreases, susceptibility to synthetic pyrethroids increases (Kurtak *et al.*, 1987). However, to avoid using all six permethrin cycles permitted each year, permethrin is generally used only at high discharges, after which all treatment can be suspended for long periods of time because the breeding sites are not productive. A pressing need to interrupt transmission occasionally leads to use of more than six permethrin cycles and costs above the permitted threshold, provided these options do not affect non-target organisms or affect them only in the short-term (these organisms can often recolonize treated areas from non-treated areas).

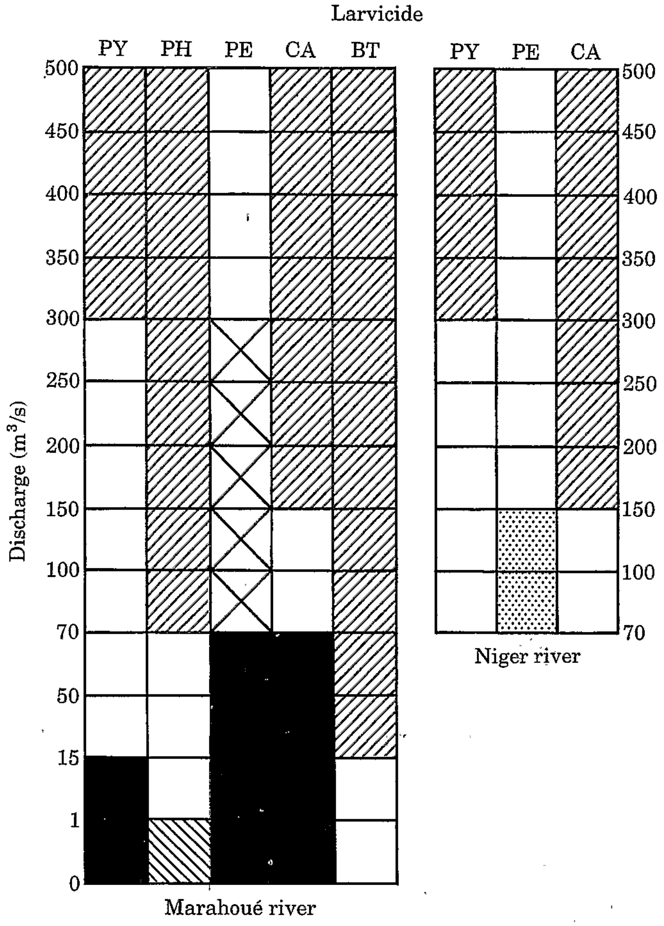

Fig. 2. The preferred insecticide(s) (□) for different discharges in the Marahoué and Niger rivers. Low cost-efficiency (▨), potential environmental damage (■), lack of accuracy in application (▧), hydrological conditions (⚄), or a particular experimental need (☒) make each insecticide unusuable under certain conditions. TE, Temephos; PY, pyraclofos; PH, phoxim; PE, permethrin; CA, carbosulfan; BT, *Bacillus thuringiensis* H-14.

DISCUSSION

We are unaware of any other vector control programme for public health in which the selection of several insecticides can be made before each treatment, based on well-established criteria. Among such criteria, the efficiency of the formulation, its toxicity to non-target fauna, the spraying system and the hydrological conditions of the river are relatively easy to assess, provided the baseline data are available. On the other hand, the likelihood of resistance to the insecticides developing and the cost-effectiveness of each larvicide are more difficult to determine because of the numerous parameters involved. The genetic and biochemical mechanisms of resistance are not yet well known and studies on the transfer of the genes involved between populations of insects are yet to be conducted (Poirié and Pasteur, 1991). Nevertheless, the use of the criteria proposed in this paper should facilitate the decision-making process.

The diagram outlining the choice of larvicide (Fig. 1) highlights two sets of conditions that are problematic in terms of treatment:

(1) Very low discharges (up to 1 m^3/s), where it is impossible to use any other product than Bt. Despite the low risk of resistance to this biocide developing (because of the mode of action of bacterial toxins), research should continue to identify other potential biological insecticides, such as *Clostridium bifermentans* Malaysia, which gave promising results in initial trials (De Barjac *et al.*, 1990), as a back up to Bt.

(2) Discharges between 15 and 70 m^3/s, at which only use of organophosphates is permitted, with all the risks of cross-resistance. It is hoped that a pseudo-pyrethrinoid compound, etofenprox (Udagawa, 1988), can also be used within this range of discharges; preliminary results indicate it would be a cost-effective alternative.

CONCLUSIONS

It is now generally accepted that the rotational use of six insecticides, although based on empirical criteria and field experience, has proved successful in the OCP area (Guillet *et al.*, 1990; Kurtack, 1990), although it may be less useful in other circumstances (Curtis *et al.*, 1993). Given the consequences of treatment failure, the strategy of rotational use of insecticides will continue. Once the selection criteria for larvicides had been defined, the decision makers could make objective selections based on cost efficiency and environmental impact. This approach has been applied successfully for several months in Mali, Côte d'Ivoire, Guinea and Sierra Leone. The next step will be the development of a computer model.

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