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5.5 *The Use of Insecticides in the Onchocerciasis Control Programme and Aquatic Monitoring in West Africa*

C. LÉVÊQUE

5.5.1 INTRODUCTION

Human onchocerciasis is a dermal filariasis widespread throughout tropical Africa. The disease is particularly serious in clinical, social, and economic terms in the Guinean and Sudanian savanna areas, where it causes irreversible blindness among exposed human populations.

The filaria *Onchocerca volvulus*, strictly limited to man, is transmitted in West Africa by the female blackfly of the *Simulium damnosum* complex (Philippon, 1977). The larvae of these flies are aquatic and occur only in fast-flowing water, requiring a minimum flow of about 50 cm/s for survival. Thus, onchocerciasis is prevalent along most watercourses, so that people have tended to leave the river valleys and move to the uplands.

In 1970, the United Nations Development Programme funded the preparation of a strategy for the control of onchocerciasis in West Africa, where about one million people have the disease. The Onchocerciasis Control Programme (OCP) was launched in December 1974 under the aegis of WHO and was planned for 20 years (Davies *et al.*, 1978). It covers a vast area of 764 000 km^2 and includes Upper Volta and parts of Ivory Coast, Ghana, Togo, Benin, Niger, and Mali (Figure 5.5.1). Up to 18 000 km of rivers with potential breeding sites for *Simulium damnosum sensu lato* were investigated and partly treated.

In the absence of any effective treatment (prophylaxis, chemotherapy) suitable for mass application, vector control is the only way to prevent the spread of the disease. Adult control being difficult, it was decided to use chemicals for controlling larval stages whose distribution is restricted to rapids.

The first insecticide treatments (Phase I) started in February 1975 in the central parts of the OCP area (Figure 5.5.2) and progressively extended eastwards (Phase II, March 1976; Phase III, July 1977), westwards (Phase III, March 1977), and southwards (Phase IV, March 1977 and April 1978). A southeastern extension was planned for 1986 in Togo and Benin as well as a western extension.

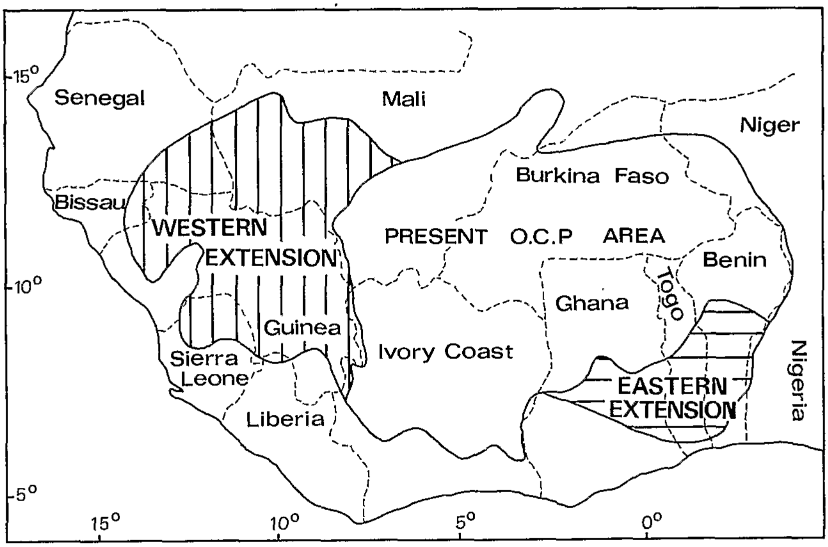

Figure 5.5.1 Present Onchocerciasis Control Programme area and extension zones planned

The OCP includes two main operational units:

(i) the Vector Control Unit (VCU) undertakes all the vector control, evaluation, and research activities and comprises three divisions: Aerial Operations; Entomological Evaluation of Vector Control; Applied Research and Staff Training. The latter coordinates and supervises studies on blackfly vectors, trials of new larvicides, and activities of the different teams in charge of the hydrobiological monitoring (see below);

(ii) The Epidemiological Evaluation Unit (EPI) responsible for the medical and parasitological assessment of the results of the VCU activities.

Several committees (Joint Programme Committee, Committee of Sponsoring Agencies, National Onchocerciasis Committees, Expert Advisory Committee) are in charge of evaluating results, providing funds for operational activities, and giving advice to WHO and the Programme Director. The Expert Advisory Committee (EAC) has attached to it a permanent Ecological Group, composed of five members, which is in charge of assessing the impact on the environment of the use of insecticides in the Programme. The Ecological Group proposes to EAC such measures as may be needed to supplement the ecological studies undertaken under the Programme and makes recommendations to ensure effective protection of the environment. The Ecological Group meets independently at least once a year.

5.5.2 TYPE OF ECOSYSTEM

The OCP covers major river systems in West Africa, such as the Volta system, part of the Niger basin and its tributaries, the northern part of Sassandra, Bandama, Comoé, Mono, and Ouémé.

Most of these rivers are savanna type with a water regime characterized by a flood period from July to December with a peak in September, and a low water period from January to March.

Many of the rivers in the central part of OCP are intermittent and dry up during the dry season. For the permanent ones, discharge is very low during that time and the upper course is sometimes reduced to a series of pools. Thus there are severe seasonal variations in flow which result in major ecological changes for species inhabiting rivers.

When the monitoring programme started, little was known about the biology of African rivers and even less about their biology when polluted. This knowledge was gradually improved and specific research was conducted for a better understanding of the results obtained in monitoring stations.

In order to help the different teams for identification of species, a catalogue of aquatic insects was produced (Dejoux *et al.*, 1981a) as well as a catalogue of fishes (Lévêque and Paugy, 1985).

Details will be found in different papers published on physico-chemistry of rivers (Iltis and Lévêque, 1982), hydrology (Moniod *et al.*, 1977), aquatic insects ecology and biology (Dejoux *et al.*, 1981a, 1981b; Elouard, 1983; Elouard and Lévêque, 1977; Gibon *et al.*, 1983; Gibon and Statzner, 1985; Statzner, 1982, 1984), fish ecology and biology (Albaret, 1982; Lévêque and Herbinet, 1980, 1982; de Mérona, 1980, 1981; de Mérona & Albaret, 1978; de Mérona *et al.*, 1977, 1979; Paugy, 1978, 1980a, 1980b), phytoplankton (Iltis, 1982a, 1982b, 1982c, 1983), river biology (Lévêque *et al.*, 1983).

5.5.3 THE AQUATIC MONITORING PROGRAMME

Since prolonged and intensive use of insecticides could present risks, it was necessary to evaluate the possible short-term and long-term effects of applications on the present organisms of the treated watercourses.

Consequently an aquatic environmental monitoring programme was devised before the beginning of OCP, so as to be sure that the insecticide released did not excessively disturb the functioning of the treated ecosystems and to provide warning to those carrying out treatments, should toxic effects be noted.

When setting up the monitoring programme, several important considerations had to be kept in mind (Lévêque *et al.*, 1979):

(i) the monitoring work was to deal with a long-term regular sampling aimed at investigating the ecological effects of treatment over the duration of the programme, combined with shorter duration research programmes looking at specific short-term problems.

(ii) the periodicity of sampling, the sites selected for monitoring, and the field methods used had to combine reliability of sampling technique with reliability of access in both wet and dry seasons, over many kilometres of roads or tracks which are not yet hard surfaced.

(iii) the monitoring techniques had to work equally well in shallow, slow-flowing rivers in the dry season and in the same rivers flowing fast and deep in the wet season.

(iv) the best possible use had to be made of the available manpower and of local facilities. The monitoring was, therefore, based on national teams of scientists from the countries concerned with OCP, with the help of foreign specialists. Many of these scientists were trained in the ORSTOM Hydrobiological Laboratory in Bouaké (Ivory Coast).

(v) in order to ensure reasonable comparability of results all teams had to use the same methods.

The monitoring programme was primarily concerned with two major categories of organisms:

(i) the benthic invertebrates that abound in the watercourses and that are directly threatened by the insecticide in the same way as *Simulium damnosum* larvae.

(ii) fishes, by virtue of their economic interest for the people living along the rivers, but also for psychological reasons to show the villages occupied in fishing that care was taken about the risks of pollution.

Shorter duration research was also conducted on water quality, phytoplankton, zooplankton, etc.

The selection of sampling stations was based on a preliminary field investigation in order to cover a wide range of river types. Some of the stations were on untreated rivers in order to act as permanent controls. Unfortunately it was not possible to collect enough ecological data to serve as reference for fauna before spraying began. The progressive extension of the OCP (Phases II–III–IV, Figure 5.5.2), however, provided an opportunity to remedy this omission, insofar as some monitoring stations were selected on rivers which had remained untreated for some years until subjected to repeated applications of temephos.

Details of monitoring and sampling methods are given in Lévêque *et al.* (1979), Dejoux *et al.* (1979), and Dejoux (1980). Only a brief summary will be given here.

For invertebrates, three main sampling methods were used:

(a) Drift net sampling using 2 m long nets, 20 × 20 cm aperture, 300 μm mesh size. Three samples were taken approximately 1½ hours before sunset (day drift) and six samples 1½ hours after sunset (night drift). River flow was measured at the time of the sampling in order to evaluate the actual numbers of animals per cubic metre filtered. The basic techniques of drift sampling used in the programme are described in Elouard and Lévêque (1977).

(b) Surber samples using a 15 × 15 Surber sampler. This simple method, which allows rocky substrates to be sampled, cannot be used in deep waters and

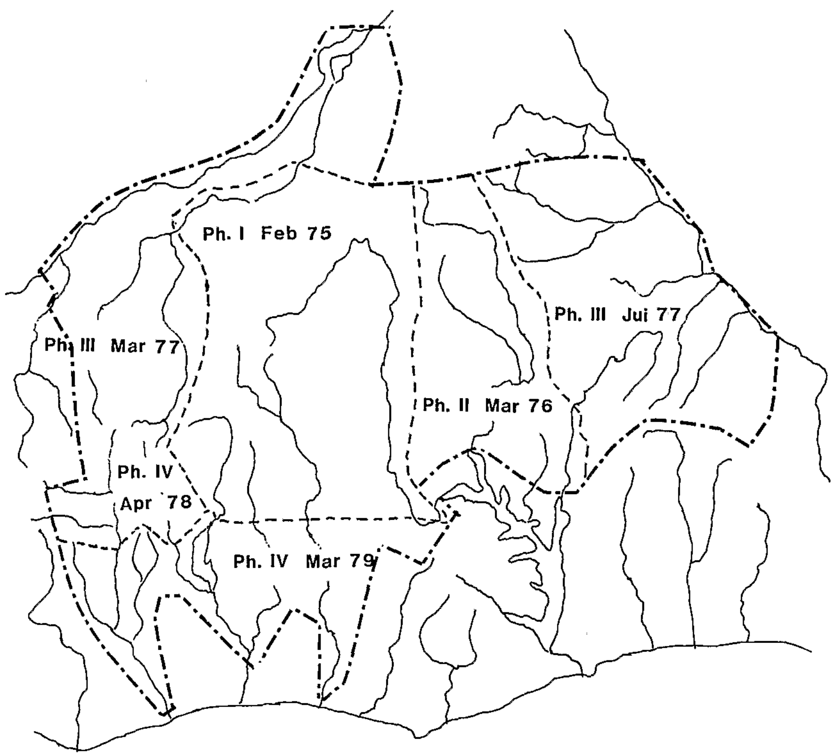

Figure 5.5.2 Chronology and extension of the different operational phases

was, therefore, limited to the low-water period. For comparative work, the results are expressed as number of animals per square metre.

(c) Artificial substrates. A special apparatus was designed for the monitoring programme. It consisted of small concrete blocks which were left immersed on the bottom for one month (Dejoux and Venard, 1976; Dejoux *et al.*, 1983). Later, other types of artificial substrates were used, such as an artificial floating substrate made of a bunch of plastic fibres (Elouard, 1983).

(d) The use of gutters *in situ* was introduced late (Dejoux, 1975; Troubat, 1981). It seems to be the most precise method for short-term study of the toxicity of an insecticide. It gives a relatively accurate picture of the mortality of organisms because the number of individuals tested is known. Moreover, the use of multiple gutters makes it possible to compare toxicity of different insecticides, or different concentrations of the same substance, with that of a control, under similar conditions.

For fishes the monitoring programme mainly concerned:

(a) the study of changes in the catch composition of experimental fishing carried out at regular intervals (3 months for the three years following the beginning of treatment, then at 6-monthly intervals) with a standardized set of gill nets.

(b) the study of some biological parameters, more especially the coefficient of condition, which is a measure of the health of fishes. This parameter may consequently be used to assess whether fishes are still able to find the food that they require in the treated rivers and whether ecological conditions remain favourable to them. It also reflects any possible adverse effect of the insecticides on the metabolism of fishes.

Complementary research was also conducted on the analysis of stomach contents of selected species, fecundity, and impact of organophosphorus compounds on brain acetylcholinesterase activity.

Data collected in the field were and are recorded on specially designed forms and sent to WHO at Geneva, where they are fed into a computer for subsequent analysis. Yearly meetings of monitoring teams have been held to discuss methods and results. Every two or three years, an evaluation of data is made by an independent group of experts, using more sophisticated statistical methods. All results are also examined by the Ecological Group.

5.5.4 SCREENING OF NEW LARVICIDES

The sequence for the development of acutely toxic chemical larvicides against *S. damnosum s.l.* follows a screening fitting into WHO's general system for the development of insecticides (WHOPES) adapted to conditions of the OCP area. These are different from those of temperate countries, especially as regards the physico-chemical characteristics of the river waters.

After different laboratory tests carried out in troughs with different concentrations, larvicides giving 100% mortality for *S. damnosum* larvae at 0.5 mg/l over 10 min (or at least 95% at 0.2 mg/l over 10 min) are tested in rivers to determine the possible operational dose. Afterwards, the impact on non-target fauna is tested in troughs at the operational dose and at twice the dose, taking temephos and chlorphoxim as controls. If the larvicide appears promising, river tests are conducted at assumed operational dose, with ecological monitoring of the river using Surber sampler, drift nets, and gutters.

The decision for operational trials depends on toxicity as regards non-target fauna, mammalian toxicity, and various technical aspects, such as ease of handling and corrosive effect of formulation. The Ecological Group proposed criteria applicable to the selection of alternative compounds for *Simulium* control:

(i) the acute effects of a candidate pesticide, in the formulation and dose rate as appropriate for its use against *Simulium*, should not reduce the numbers of invertebrate species to a level at which their survival at a given locality would be endangered.

(ii) the pesticide should not give rise to the regional loss of any invertebrate species; the temporary seasonal local disappearance of some invertebrate species at the breeding sites of *Simulium* may have to be accepted.
(iii) the pesticide should not cause a long-term (i.e. extending beyond the next season) imbalance under normal conditions of application, e.g. marked shifts in the relative abundance of species should not occur.
(iv) The use of the pesticide should have neither any direct impact on fish nor any effect on the life cycle of fish.
(v) compounds likely to accumulate in the food web should be avoided.
(vi) in the process of selecting pesticides for *Simulium* control in an area, full account should be taken of human activities which either by themselves or in combination with the vector control operations might cause adverse effects on the environment.

A hundred insecticide formulations have been tested by OCP during recent years. Many of them were not completely effective against *Simulium* larvae. Few were tested with non-target entomofauna (Dejoux 1983b; Dejoux and Troubat, 1982; Paugy *et al.*, 1984; Troubat and Lardeux, 1982; Yameogo *et al.*, 1984) but were not selected due to their toxic effects. Many others are still under screening.

It should be noted that different methoxychlor formulations were not completely successful in *Simulium* larvae control, whereas good results were obtained in Canada and the USA. The reason should be a decrease in activity where temperature increases. The inverse phenomenon is observed for organophosphorus compounds, temephos giving feeble results in temperate zones.

5.5.5 POLLUTANT INPUT

The insecticide selected for a large-scale campaign of this type, due to last for about 20 years, must have properties that allow it to meet often contradictory requirements, such as effective action against the larvae of *S. damnosum*, ease of application, lowest possible cost, little residue but far-reaching effect, harmlessness for man and mammals, and lowest toxicity possible for the rest of the aquatic environment.

An organophosphate, temephos (or Abate®), was selected according to the above criteria, after numerous laboratory and field tests, on account of its efficacy against the larvae of the vector and its low toxicity for the non-target fauna (Dejoux and Troubat, 1973, 1974; Lauzanne, 1973; Lauzanne and Dejoux, 1973).

A 20% emulsionable concentrate is used for operational activities. The dosage of 0.05 ppm/l over 10 min is effective for about 40 km in the wet season. In the dry season, treatments tend to be made to each riffle and the dosage is normally 0.1 ppm/l over 10 min.

Temephos was the only insecticide used between 1974 and 1980. In December 1979 temephos resistance developed in the species *S. soubrense* and *S. sanctipauli* from the *S. damnosum* complex, in breeding sites of the lower Bandama (Ivory Coast). This resistance spread rapidly to the southern forest zone and part of the humid savanna zone in the rainy season, but has not appeared so far in the savanna species *S. damnosum* and *S. sirbanum*, which are encountered in the main part of OCP. Consequently, insecticides other than temephos have been used for controlling the resistant species so as to maintain efficacy. They are:

(i) *Bacillus thuringiensis* serotype H-14, a spore-forming bacterium. At sporulation, each bacterium produces a crystal of toxic protein, lethal to larvae upon ingestion. B.t. H-14 is highly host-specific, unlike broad-spectrum insecticides. Unfortunately it can be used until now only in the dry season because of the low concentration of active ingredient in available formulations, which makes it unusable in the rainy season with the logistic resources available to OCP. The commercial formulation used in the OCP area is Teknar, but the search for better B.t. H-14 formulations would appear to be the best approach to find an insecticide as a real replacement for temephos.

(ii) Chlorphoxim is another organophosphate. A 20% emulsionable concentrate is used at the dosage of 0.025 ppm/l over 10 min. This pesticide is more toxic than temephos but a resistance developed in the forest species already resistant to temephos, around July 1981. Fortunately, the resistance to chlorphoxim is less stable than resistance to temephos, and regresses when treatment is stopped.

In 1984, temephos was still used in three-quarters of the OCP area. In the south-west where strains resistant to this larvicide appeared, Teknar is used at river discharge of up to 200 m^2/s. Above this level, chlorphoxim is substituted.

Since larval development is short (around 10 days) weekly spraying has proved necessary for effective control of vector populations in breaking development cycles of blackflies. To cover the area, vector control has been carried out by aerial applications of larvicides, using six to nine helicopters and one or two specially equipped fixed-wing aircraft, depending on the season.

An estimate of the amount of insecticides used in OCP from 1975 to 1983 is given in Table 5.5.1. It is clear that B.t. H-14, the less toxic larvicide, is increasingly used in the OCP area.

5.5.6 EFFECTS NOTED

5.5.6.1 Invertebrates

Temephos

A routine spraying operation (0.05–0.1 mg/l over 10 min) produces a massive detachment of insect fauna, reflected by a rise in the drift, after a 15–45 min

Table 5.5.1 Amount of insecticides (10^3 l used in the OCP area from 1975 to 1983. Sources: OCP, 1983)

	1975	1976	1977	1978	1979	1980	1981	1982	1983
Abate 200 C E*	75	130	156	216	263	184	132	163	120
Chlorphoxim*						6	81	7	22
B.t. H-14 (Teknar)†						0.5	8	233	290

*For Abate and chlorphoxim an emulsionable concentrate (20% active ingredients) was used throughout the period
†For Teknar, concentration was 3000 units *Aedes aegypti* per mg

period of latency (Dejoux, 1983a). Regular evaluation of the mortality rate of drifting organisms has shown that within 5 hours of treatment nearly 100% were dead. The mortality rate was reduced to 75% during the following hours and to nearly zero 24 hours after application of insecticide (Dejoux, 1982). Generally speaking, the first applications of temephos in rivers have a fairly strong effect, and 30 to 50% of the invertebrate population (experimental data) release their hold on their substrate at low-water period. Subsequent applications have a less quantitative impact because there is some selection of the least susceptible species and the most resistant ones (Dejoux, 1983a).

Although all taxonomic groups are affected, some of them, such as the Tricorythidae and some Batidae (Ephemeroptera), some Philopotamidae and Leptoceridae (Trichoptera), are particularly susceptible to temephos. The taxa with moderate susceptibility include the Hydropsychidae (Trichoptera), Caenidae (Ephemeroptera), and *Simulium* species other than *S. damnosum s.l.* The chironomids display little susceptibility to this insecticide (Dejoux, 1983a; Dejoux *et al.*, 1980; Elouard, 1983, 1984a; Elouard and Jestin, 1982, 1983; Samman and Pugh Thomas, 1978).

It has also been observed that there are variations in susceptibility during the various larval stages. Early stages are much more seriously affected by temephos than older organisms (Elouard, 1983).

Evaluation of the quantitative variations produced by temephos in the long term gave an overall value of 40% reduction in the quantity of fauna. But this value should be regarded as relative because it includes both insects which have proliferated and those which have greatly diminished due to the insecticide. In fact, in a monitoring programme applied on such a vast scale, with such wide seasonal fluctuations and variations in distribution, it seems difficult to quantify the long-term effects of temephos in terms of variations of population densities. On the other hand, long-term structural variations in population are more easily identified. This is due to the establishment of stable biocoenotic structures which are typical of temephos treatment periods and different from those observed in untreated rivers or during periods without treatment (Elouard and Jestin, 1982, 1983).

The most obvious indicators of long-term modifications are the disappearance of *Simulium adersi*, the rarefaction of Trichorythidae and of some species of Batidae (*Pseudocleon* sp., *Centropilum* sp.), and the proliferation of *S. schoutedeni* and the Chironomidae.

It should be noted that the nycthemeral pattern of drift does appear to be affected by temephos, being less marked and becoming even patternless after several months of treatment.

B.t. H-14

All the tests and field experiments carried out in the OCP area shown that B.t. greatly affects all *Simulium* larvae but is safe for most of the non-target invertebrate fauna with the exception of a few taxa, such as *Orthotrichia* (Trichoptera) (Dejoux *et al.*, 1985; Gibon *et al.*, 1980; Dejoux, 1979; Elouard and Gibon, 1984). According to Rishikesh *et al.* (1983), this larvicide is an exceptionally safe agent for non-target organisms, including man and other vertebrates.

Field experiments showed that drift of invertebrates after application of B.t. behaved very differently from the drift observed when organophosphorus insecticides were applied. The maximum drift following application was very low, below the night peak for the control drift. That is another proof of the low toxicity of this larvicide.

Chlorphoxim

All the observations show that this insecticide is much more toxic in the short term than temephos for the non-target invertebrate fauna. All insect taxa are affected except for the Orthocladiinae (Chironomidae) and the Caenidae (Dejoux *et al.*, 1981c, 1982; Elouard and Gibon, 1984; Gibon and Troubat, 1980).

Alternation of insecticides

An interesting question was to know if alternation of insecticides would permit the recolonization of treated stretches by groups partly eliminated by the use of a single insecticide or if, conversely, the alternation would have an even more catastrophic effect on the non-target fauna.

The results obtained during the fairly intensive study conducted in the lower Maraoue river (Ivory Coast) are quite reassuring. The river has been monitored since 1975 and treated with temephos from March 1979 to August 1980. Then since November 1980, as a consequence of the appearance of temephos resistance in the complex *Simulium soubrense*—*S. sanctipauli*, three insecticides have been used alternately: temephos, chlorphoxim, and B.t. H-14.

After four years of larvicide treatment, it cannot be said that repeated weekly insecticide applications have an effect on the population densities for the taxonomic groups as a whole (Elouard and Gibon, 1984). For the major groups, the seasonal variations in numbers observed during the pre-treatment years are in most cases of the same order of magnitude as those observed after larvicide treatment. But that does not mean that there has been no impact. As regards the Chironomidae, their densities increased substantially whatever insecticide was used. For the Batidae and possibly for the Tricorythidae, it would seem that the use of insecticides, particularly chlorphoxim, was producing a gradual reduction in their numbers. But the wide fluctuations in density of these taxa which were observed during the pre-treatment period prevent any definitive conclusion on this point.

With all the results being expressed at family level, it must also be pointed out that an increase in the density of one or more species may mask a decrease or even the disappearance of other species. Thus, the very high densities of Hydropsychidae (Trichoptera) observed in 1981–1982 are due to the genus *Cheumatopsyche*, while all the available data (Statzner and Gibon, 1984) indicate that since larvicide treatment began, there has been a substantial regression of the Macroematinae, particularly the genera *Macronema* and *Protomacronema*.

The overall conclusion of this study is that alternation of the insecticides as practised by OCP in the lower Maraoue does not appear to disrupt the population of aquatic insects to a greater or lesser extent than each of the insecticides alone.

5.5.6.2 Fish

From the results obtained in the course of monitoring rivers treated with temephos in the OCP area, the overall conclusion was that temephos had no detectable effect on the fish populations (Abban *et al.*, 1982; Lévêque *et al.*, 1982). There were no major changes in the size of the experimental fishing catches in monitoring stations as illustrated in Figure 5.5.3. Some changes observed in the composition of catches were not ascribable to the insecticide but rather to year-to-year changes in river discharge. This is the case, for instance, for *Schilbe mystus*, which disappeared almost completely after the flood in 1976, both from treated and untreated rivers, and reappeared in abundance by the end of 1979 (Lévêque and Herbinet, 1980).

The analysis of stomach contents carried out in 1975 on different species in treated and untreated rivers did not provide evidence of an influence exerted by the insecticide since the diet was appreciably the same in composition whatever the provenance of fishes (Vidy, 1976). This result was confirmed in 1976 and 1977 (unpublished data).

For the coefficient of condition, results obtained in various basins show that values are relatively random, fluctuating around a mean, for each species concerned; they did not seem appreciably altered after five years of monitoring.

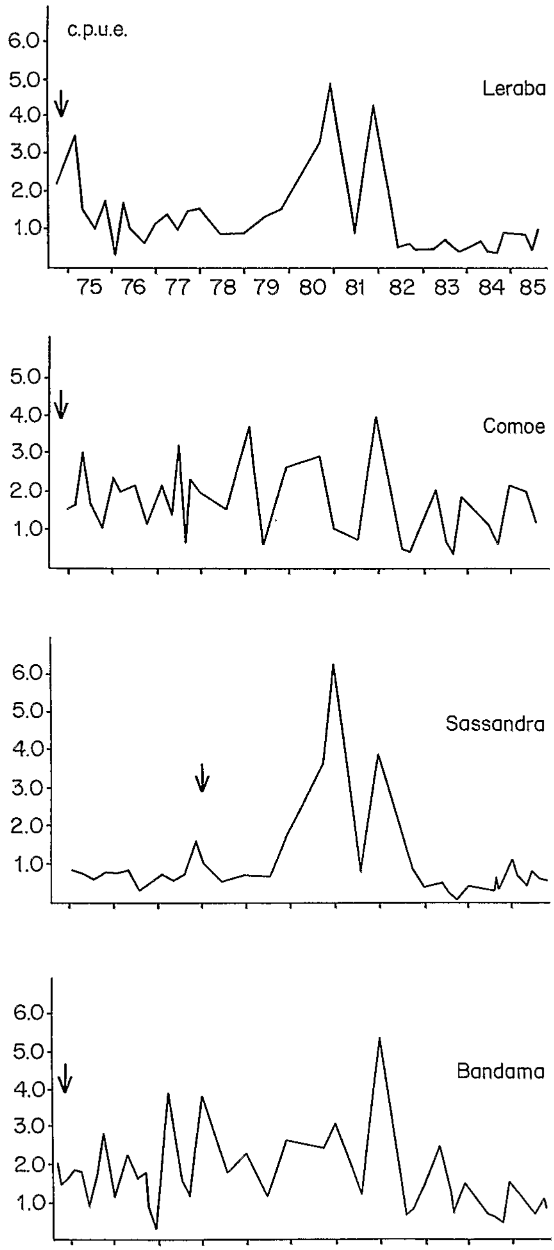

Figure 5.5.3 Changes in total catch per 100 m of gill net per night in experimental fishing for different rivers treated. The arrow indicates the beginning of insecticide application

Studies on fecundity of the principal species showed no differences between fishes from treated or untreated basins.

But even if temephos does not seem to affect fish, it can accumulate in tissues, as shown by some results obtained during the dry season in the OCP area (Quelennec *et al.*, 1977): the concentration of temephos (in ppm) one day and six days after spraying was, respectively, 14.3 and 7.1 for *Tilapia zillii*, 0.77 and 0.25 for *Alestes nurse*, and 1.3 and 0.96 for *Labeo parvus*. Much lower values were obtained for *Tilapia zillii* during flood.

Since toxicity of organophosphorus compounds is due mainly to their inhibitory effect on cholinesterase activity, a study on the effect of temephos on brain acetylcholinesterase (AChE) activity of fish was conducted in the OCP area (Antwi, 1983, 1984). No inhibitory effect was found in the brain AChE activity of *Alestes nurse*, *Schilbe mystus*, and *Tilapia* spp. in rivers treated for many years with temephos. But some *Tilapia galilaeus* and *Alestes nurse*, caught 24 hours after chlorphoxim application in the Maraoue river, showed a 20% reduction in the brain AChE activity.

5.5.6.3 Others

Studies on phytoplankton in Ivory Coast (Iltis 1982a, 1982b, 1982c; 1983) did not show any noticeable changes in species composition or biomass in rivers treated with temephos.

5.5.7 RECOVERY AND REVERSIBILITY— THE RECOLONIZATION POTENTIAL

The results obtained in the monitoring programme for treated rivers in the OCP area clearly demonstrated that on a long-term basis, the impact of insecticides was far from drastic. A good illustration is given by results obtained during the detailed study of the Lower Maraoue (see above). But it appears also that recolonization potential is high among invertebrates in rivers treated with temephos. That is the case, for instance, with the Red Volta, an intermittent river treated from 1976 to 1981. The structure of invertebrate populations during that period was typical of the treated rivers, namely with predominance of Oligochaeta and chironomids. The river was not treated in 1982 and the population structure was therefore similar to that found in untreated sites (Guenda, 1985).

Some data are also available for rivers treated with chlorphoxim. The Bandama basin was subjected to six to eight cycles of chlorphoxim treatment, depending on breeding sites, from 18 November 1980 to 6 January 1981. In the course of the campaign, this insecticide reduced the density of the fauna colonizing rocky substrates by 75 to 98% (Dejoux *et al.*, 1981c). Nevertheless, a week after the larvicide was discontinued there was a spectacular rise in densities, but the community structure was different from that customarily observed on these rivers, whether untreated or treated with temephos. The situation seems to return to normal within one or two months after suspension of treatment.

The recovery capacity of the invertebrate fauna in the rivers under study appears to depend on the existence of refuge zones and their capacity to fuel the recolonization of stretches of water that have been depopulated by insecticides. The problem of recolonization is probably highly complex, with different mechanisms being involved (Elouard, 1984b):

(i) a number of tributaries and some of the upper reaches of large watercourses are free of breeding sites for *S. damnosum* and are not treated with insecticide. They may, therefore, serve as refuge areas or rather as nurseries for recolonization by non-target fauna. A study carried out on the tributaries of the N'zi in Ivory Coast (Gibon *et al.*, 1983) demonstrated that the fauna found in the small tributaries was taxonomically very similar—as far as the running-water fauna is concerned—to the fauna found on the treated stretches of water. These small untreated watercourses could, therefore, act as reservoirs and ensure the survival of the non-target fauna.

(ii) in large rivers, there are some stretches of water flowing too slowly to permit the development of *S. damnosum s. l.* On the other hand, neither do they permit development of most of the non-target fauna. These stretches are generally not treated by OCP and constitute excellent potential reservoirs.

(iii) as far as insects are concerned, treated stretches as well as temporary watercourses could be recolonized from the air by imagoes from untreated rivers, either inside or outside the OCP area.

Moreover, in the central parts of OCP, where so far control has been very successful, there has been considerable reduction in treatment over the last few years. Systematically, weekly treatment has been replaced by 'opportune' treatment carried out only when *S. damnosum s.l.* are present. Walsh (1981) evaluated the length of rivers in the central parts of OCP (Phases I, II, III) as approximately 8000 km in the dry season and 23 000 km in the wet season. During the first years, respectively 5500 and 14 000 km of rivers were treated, but in 1980 only 4500 and 11 400.

In 1983, owing to a particularly favourable dry season and better utilization of the existing knowledge, Teknar and temephos treatments were progressively curtailed so that only 600 km of the Bandama river system, in the Control Programme area, were treated using Teknar only at the time when the water level was lowest.

The lightening of insecticide pressure on the rivers is most favourable to the maintenance of the non-target fauna.

5.5.8 CONCLUSIONS

Throughout the history of OCP, considerable attention has been given to the possible effects of larvicides on the non-target fauna and river biology. It is probably the only major programme to date with such an environmental monitoring element within its own structure.

The results obtained after many years' treatment lead us to assume that the larvicides employed had little effect on the non-target fauna. Although the first applications of temephos and chlorphoxim had a fairly strong impact on invertebrate communities in the short term, it would seem that these situations disappear fairly quickly after a year or less of successive applications. In operational conditions, the treated rivers seem to have fairly strong resilience, and at any rate a great capacity of recovery.

The situation is still improving with the reduction of treated rivers, resulting from the success of vector control, and increasing utilization of B.t. H-14, an exceptionally safe pesticide for non-target fauna.

But environmentalists are also concerned with the considerable quantities of pesticide locally available for agricultural purposes, and with the danger of fish poisoning in the Programme area caused by abuse of them. The attention given by OCP to protect the aquatic environment could be completely jeopardized by uncontrolled pesticide practices, which seem to be relatively common within the area.

5.5.9 REFERENCES

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