Impact of temephos (Abate) on the non-target invertebrate fauna

A — Utilization of correspondence analysis for studying surveillance data collected in the onchocerciasis control programme (1)

Jean Marc Elouard (2) and Jean Marie Jestin (3)

Summary

During six years of insecticide application against Simulium damnosum s.l., *the side effects on the non-target macroinvertebrate fauna have been monitored. Using the correspondence analysis (reciprocal averaging), the authors point out the evidence of a long term effect of the pesticide (temephos) and consider the validity of the methods used for invertebrate sampling.*

The correspondence analysis of the data from Surber samples shows a modification in the population structure occurring after temephos treatment as well as a seasonal pattern. The substitution of an abundance quotation (i.e. codification) for the original counts does not modify the established typology.

The target species Simulium damnosum s.l. *and the species* Tricorythus sp. *(Ephemeroptera) appear to be the most sensitive organisms, and the density of Chironomidae and especially Tanytarsini rise markedly after treatment. The proportions of Baetidae and Hydropsychidae are lightly affected by the pesticide.*

Parallel studies carried out at a specific level of identification have shown that certain phenomena are masked in the monitoring results by the grouping of several species within the same taxon. The central position on graphs and thus the presumed insensitivity of Simuliid species other than S. damnosum *is, in fact, the result of a variation in susceptibility amongst the species.* S. adersi *being sensitive,* S. schoutedeni *resistant and S. tridens* apparently *unaffected.*

The use of a calculated index of pollution resulting from the factorial axis of susceptibility obtained with coded data in the correspondence analyses, is proposed.

Key words : Onchocerciasis Control Programm — Temephos — Non-target fauna — Lotic communities — Correspondence analyses — Pollution index — Ivory Coast — Africa.

Résumé

Impact du téméphos (Abate[R]) sur les invertébrés non-cibles. A — Utilisation de l'analyse des correspondances pour analyser les données de surveillance récoltées dans le programme de lutte contre l'Onchocercose dans le bassin de la Volta

En Côte d'Ivoire, après six années de surveillance des milieux lotiques traités au téméphos dans le cadre du programme de lutte contre l'Onchocercose dans le bassin de la Volta, les auteurs mettent en évidence, à l'aide de l'analyse factorielle des correspondances, un impact à long terme du pesticide et s'interrogent sur la validité du protocole d'échantillonnage choisi pour la récolte des invertébrés.

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(2) *Entomologiste médical O.R.S.T.O.M. Laboratoire d'Hydrobiologie de Bouaké, B.P. 1434 (Côte d'Ivoire).*

(3) *Laboratoire d'Écologie hydrobiologique. ENSA. 65, rue Saint-Brieuc, 35042 Rennes Cedex, France.*

Une analyse factorielle des correspondances effectuées sur des données recueillies à l'échantillonneur de Surber montre une modification de la structure des peuplements après traitement au téméphos ainsi qu'une saisonnalité marquée. L'utilisation d'une cotation d'abondance ne perturbe pas la typologie établie. L'« espèce » cible Simulium damnosum s.l. *et un Éphéméroptère,* Tricorythus sp. *apparaissent être les plus sensibles, par opposition aux Chironomidae et plus particulièrement aux Tanitarsini, dont la proportion dans les échantillons augmente notablement après traitement; Baetidae et Hydropsychidae réagissent peu à l'insecticide.*

Il est également démontré que certains phénomènes sont masqués du fait du regroupement de plusieurs espèces dans un taxon. Ainsi, la position centrale dans les représentations graphiques et donc l'insensibilité présumée des Simulies autres que S. damnosum *résulte de la sensibilité variable des espèces concernées, sachant que l'on peut qualifier* S. adersi *de sensible,* S. tridens *d'indifférente et* S. schoutedeni *de résistante.*

Les auteurs proposent l'utilisation d'un indice synthétique de pollution issu de l'axe factoriel de sensibilité obtenu avec des données codées.

MOTS-CLÉS : Programme de Lutte contre l'Onchocercose — Temephos — Faune non cible — Communautés lotiques — Analyse des correspondances — Indice de pollution — Côte d'Ivoire — Afrique.

For the past six years the World Health Organization (WHO) has undertaken the control of human Onchocerciasis in West Africa. Because of logistic and economic considerations, an organophosphorous larvicide, temephos (Abate[R]), has been used in the control programme. Weekly treatments of all potential breeding sites of *Simulium damnosum s.l.* within the control area are required because of the brievity of the larval cycle of these black fly vectors. The insecticide concentrations range from 0.05 to 0.1 ppm which are active against the vector show some effect on the other benthic invertebrate fauna.

Such systematic riverine pollution over several years poses a threat to the lotic ecosystem involved. In order to predict and prevent eventual ecological long term catastrophy, ecological surveillance has been conducted during the past five years.

From numerous past experiments both in experimental gutters and *in situ* (DEJOUX, 1977a; DEJOUX, 1977b; DEJOUX et ÉLOUARD, 1977; ÉLOUARD et FORGE, 1977; DEJOUX, 1978a; DEJOUX, 1978b) we already knew that temephos presented a certain amount of short term toxicity for the non-target insect fauna. Therefore, it was important to know if this non-catastrophic and limited effect would have serious long term repercussions. The mathematical treatment of surveillance data should, therefore, answer the following questions:

— Does temephos have a long term effect on the benthic fauna?

— Was the protocol for ecological surveillance of the rivers adopted after the beginning of the programme, adequate for the evaluation of such an effect? Because the sampling techniques employed were, in fact, chosen *a priori* at the start of the programme, and it was not evident that these techniques were sensitive enough to demonstrate evidence of a low magnitude change attributable to Abate, especially if these could be masked by strong natural variations due to the effects of seasonal abiotic factors (ÉLOUARD *et al.*, 1979).

The large quantity of data collected both on treated and untreated rivers, during five years of monitoring enable us to answer these two questions. However, up to now, and because of the too many factors involved in the natural ecosystem variations, we cannot prove any long terme effect of the temephos on the non-target fauna with the classical methods of data analysis. For such data, we think we need multifactorial analyses which allow to point out and to grade easily the main factors interferring. Such analysis match very well the problems induced by the monitoring data. Indeed the heading word "multifactorial analysis" covers several methods. Two of them have been tried: the principal component analysis (PCA) tested by the Salford mathematical team and the Factorial correspondence analysis (FCA) tested by the Bouaké hydrological team. Up to now, only this last method has given valuable results as far as temephos is concerned.

It is not the purpose of this publication to detail the results obtained through the AFC method, but the aim is to prove, with example, the usefulness and reliability of such a method in the interpretation of the data collected in the African river monitoring programme. We shall expose the results of the temephos impact in a further publication.

1. METHODS

1.1. Choice off sampling station and data to be utilized

The principal criterion in the choice of stations was the existence of pre- and post-treatment surveillance data. Consequently the data studied were selected from:

— Danangoro site (DAN) (Maraoué) under surveillance since 1975. The data considered for this study are from 1976 to 1980, say 3 years before and one year after the treatment which began in March 1979.

— Entomokro site (ENT) (Maraoué) under surveillance since 1978 and under treatment since March 1979.

— Semien site (SEM) (Sassandra) under surveillance since late 1977 and regularly treated since 1978.

An empirical knowledge of the field situation has permitted the selection of the most appropriate months and sampling techniques. Later, certain more objective criteria, based on sample counts and homogeneity of data, justified our empirical choice of techniques (Dejoux *et al.*, 1980).

Thus, the months of January, February, March, November and December of each year were chosen for analysis. In Ivory Coast, they correspond to the period of decreasing stream level and the beginning of the dry season. At that time, the benthic fauna is at maximum density and species richness. To illustrate the correspondence analysis method, we only consider in this paper the data obtained from Surber samples. Only the 18 taxa presented below occuring in sufficiently high numbers were used in the analysis.

Ephemeroptera
- Baetidae.......... (BAE)
- Caenidae.......... (CAE)
- Tricorythidae...... (TRI)

Trichoptera
- Hydropsychidae... (PSY)
- Ecnomidae........ (ECN)
- Hydroptilidae..... (PTI)
- Leptoceridae...... (LEP)
- Philopotamidae.... (PHI)
- Polycentropodidae. (POL)

Lepidoptera
- Pyralidae......... (PYR)

Diptera
- *S. damnosum s. l.* (DAM)
- Simuliidae*..... (SIM)
- Chironomini..... (CHI)
- Tanytarsini..... (TAR)
- Orthocladiinae... (ORT)
- Tanypodinae.... (POD)
- Other Diptera... (OTH)

Neuroptera
- Sisyridae (SIS)

Acarina
- Hydracarina..... (HYD)

* Other than *S. damnosum*

1.2. Nature and quality of the data

Within the surveillance protocol adopted, the fauna collected with the different methods was identified to various taxonomic levels depending on the group considered. This level ranges from species *(S. damnosum)* to family (Baetidae) or even sub-class (Acarina).

The data used for the present analysis were grouped in a faunistic table representing the relative abundance of the 18 taxa. The physical variables used only served for the identification of the samples (stations, dates of collection and eventual treatment with temephos). The row of the table represents the different observations or sample collections while the columns represent the taxa.

The quality of these data is influenced by the level of identification chosen for each taxon and depends upon the sampling techniques. Surber samples, for example, permitted an estimation of the density of invertebrates on the rocky substrates but the precision of this estimation depends on the size of the sample (number of replicates) and on the distribution of the organisms collected (regular, random or aggregated distribution). In lotic environments aggregated distributions predominate and in this case 5 replicate samples, such as we used, only provide low precision.

In addition to the direct toxic action of temephos on certain taxonomic groups there may also be an indirect action of temephos caused by modification of the food web or by territorial competition. The pesticide can favor or disadvantage certain groups, thereby, profoundly changing the structure of communities. It appears to us to be more suitable to study the structure of invertebrate communities rather than the change in density of isolated taxa ; these studies are based on the variations of the relative abundance. Papers on similar studies have already been presented (Vernaux et Tuffery, 1967; Chutter, 1971) establishing a classification of water quality by means of synthetic indices.

Factor analysis are well adapted to this category of statistical material because they permit the description of multidimensional reality.

Under the heading factor analysis there are several techniques presenting a common group theory. Among these we have preferred the correspondence analysis (FCA) which applies well to contingency table (or crossed tables) (Benzecri & *coll.*, 1973; Hill, 1974). The algorithms and the logical programmes used are those described for the AFC in Lebart *et al.*, 1977.

Fig. 1

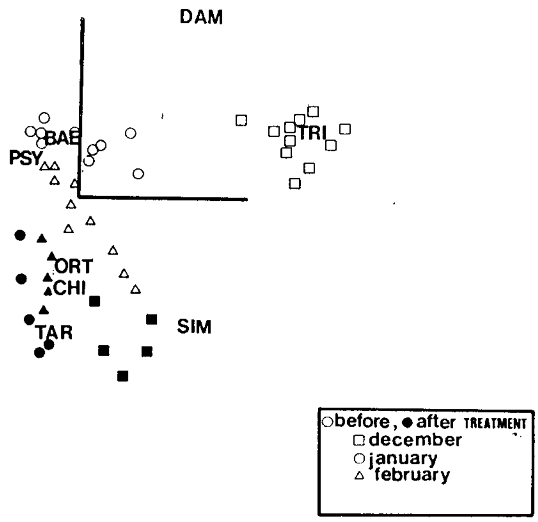

Fig. 2

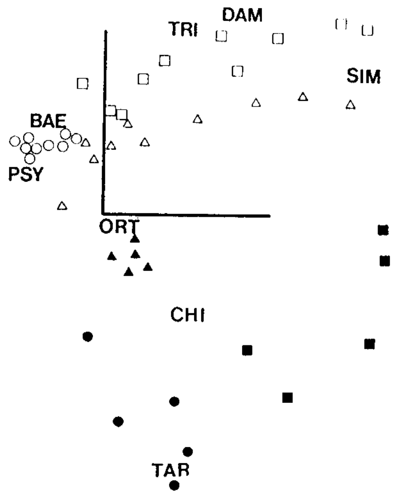

Fig. 1. — Sample collections of Entomokro. Factorial plane 1×2

Fig. 2. — Sample collections of Entomokro. The variable Tricorythidae (TRI), and the sample collections of Semien as supplementary element. Factorial plane 1×2

2. RESULTS

2.1. Analysis on raw data

The group consisted of 185 Surber samples, in which the numbers of the 18 selected taxa have been recorded, constitutes a matrix of 185×18. The first analysis (FCA I) was carried out on these non-transformed data. The projection of the points on the factorial plane 1×2 is represented in fig. 1. In order to assure the best legibility, the sampled points were split according to the stations. The darkened symbols correspond to samples collected during the treatment. The samples of the three stations Danangoro, Entomokro and Semien contribute to the results in the FCA I but only the Entomokro site is represented in the graph.

In the FCA I, the first two factors building the first two axes account for 40.3 % of the total variance. Let us emphasize, however, that this percentage gives a pessimistic idea of the part of information supplied by the factors. On the first axis, there is a strong opposition between the variables TRI and SIM to PSY. The other variables occur to a lesser extent in the axis. The second axis is positive for variables Baetidae and Hydropsychidae and negative for Tanitarsini.

On the other hand, the samples are clearly separated as a function of the treatment. The points corresponding to the periods under treatment appear more often negative on the second axis. However, we must also consider the influence of traditional fishing using botanical poisons which takes place each year at the same time on the Maraoue. The larvicidal effect of fish poisoning is similar to the marginal effect of Abate, and this explains the similar positions of samples collected in February before and after the beginning of temephos application.

If the interpretation of this analysis is satisfactory, one can examine the stability of established typology. In fact the investigation of the absolute contributions of variables on the axis show that the variable Tricorythidae (TRI) with an absolute contribution of 62 % to the primary axis is an element which threatens the stability of the analysis (Escoffier & Leroux, 1976). This variable which is strongly associated with the month of December (cf. fig. 1) is an important seasonality factor. Thus, for axis 1, where the influence of Tricorythidae is a deciding factor, the effect of treatment and of the season interfere with one another.

In order to have a very solid base of interpretation it is usual to suppress such elements. They no longer act in the construction of the factorial axis, but can be projected on the new axes. They are then considered as supplementary elements.

One can thus expect clarification by introducing the variable Tricorythidae as a supplementary element. Likewise, in this second analysis (FCA II), the samples of the Semien station were introduced as supplementary elements. The variables Simuliidae, Tanytarsini, Hydropsychidae and Baetidae provide a balanced contribution on the first axis (fig. 2). The contrast is clear : one finds the species which are indifferent to the action of Abate negatively represented thereby holding the populations relatively constant, before and after treatment; in contrast the sensitive taxa, Tanytarsini, Simuliidae, are positively represented. Their presence means that they may be favoured or disadvantaged by the treatments. *Simulium damnosum*, Chironomini and Orthocladiinae, react in the same way, although they represent a smaller contribution to this axis.

In this second analysis, the first axis therefore expresses a constant factor of stability. The second axis discriminates between the favored taxa (essentially Tanytarsini and Chironomini) and the other sensitive taxa (*S. damnosum* and Simuliidae) which disappear after the action of temephos. We are hence in the presence of a veritable "axis of treatment" with the samples corresponding to the treated period appearing in the lower part of the figure. Again the situation is more confused for the month of February. The effects of traditional fishing and pollution due to Abate are hard to separate.

2.2. Coded data (FCA III)

Coding is often practised by data analysts. Though it involves a loss of information, results may be obtained which are very close to those provided with raw data (FRONTIER & IBANEZ, 1974; FRONTIER & VIALE, 1977). The established typology is the same, but the percentages of inertia of factors are weaker. This confirms the pessimistic character of this measurement as already discussed.

A step of this nature is well adapted to our problem. In fact we have underlined the lack of confidence which must agree with the absolute values obtained so far as estimations of population levels. It was therefore attempted to substitute computations with a code corresponding to the usually adopted semi-quantitative scale: 0 for absence, 1 for 1-9 individuals, 2 for 10-99, 3 for 100 or more. Thus the transformed table was analysed maintaining all of the individuals and variables (no supplementary elements).

Figure 3 where the samples are only referenced to by the absence or the presence of treatment is significant. Axis I constitutes an axis of treatment. The almost central position of the point *Simulium* other than *S. damnosum* appears to indicate that the treatment has no effect on this taxon. Sample

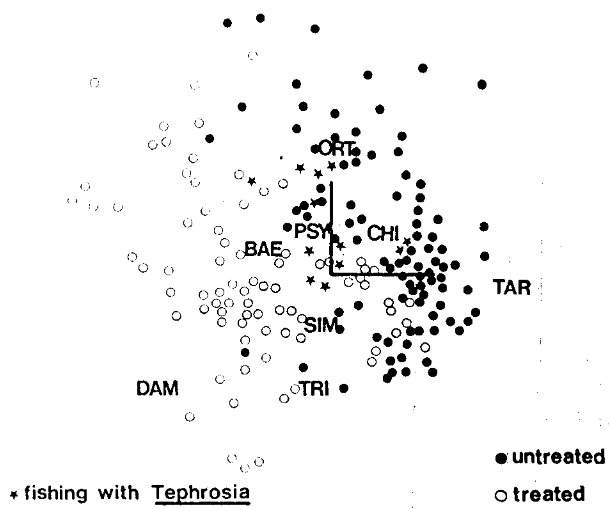

FIG. 3. — Sample collections of Danangoro, Entomokro and Semien. Analysis with coded data. Factorial plane 1×2

analysis carried out at a species level, will allow a better understanding of this strange situation. The variables Trichorythidae and Orthocladiinae only appear in the second axis probably connected with the seasonality and the differences between stations.

2.3. Pollution index

The discriminant ability of the first axis translating the susceptibility allows the construction of a variable, which is a linear combination of the analysed units, and can be considered as an indicator of Abate pollution.

This function has the same discriminant power as the discriminant linear function of Fisher (BENZECRI, 1976). From a description of a sample according to a semi-quantitative scale, one can then reveal, in calculating this synthetic index, the impact of Abate.

Such an index based on the results of a factorial analysis was used with samples of Algae by DESCY (1976). The result is very close to the "Saprobic index" but based on objective and precise criteria.

The qualities of such an instrument of analysis described by LEBART *et al.* (1977) are: precision, stability, easy utilization and large susceptibility.

This linear combination corresponds for one replicate to its projection on axis 1 and the coefficients affected to each variable are the component score on axis 1. If a_j is the coefficient corresponding to the variable j, k_{ij} is the abundance of species j in the sample i and IND (i) is the index for sample i:

$$IND\ (i) = \Sigma_j\ a_j\ k_{ij} \times 1/k_i$$

The term $1/k^1$ corresponds to the weighting by the total count of the sample. Based on the analysed data it is possible to calculate the coefficient of each taxa as following :

BAE = —0.3	PHI = 0.2
CAE = —0.1	CHI = 0.2
ECN = —1.2	TAR = 0.8
PSY = —0.1	POD = 0.2
PTI = —0.2	SIS = 1.2
LEP = —0.4	HYD = 0.3
DAM = —1.1	

Because of the too central position of the five other taxa, their coefficient value are equal to zero and are not taken into account.

Of course this index needs further confirmation which will be done by analysis of samples collected at other sites. The result is more reliable when the calculated value differs from zero. This appears clearly in fig. 3 where some points related to an untreated period can have a positive value on this axis. Thus, these samples are not correctly ranked but the value of the index is near zero.

2.4. Comparison with coded data classified to a specific level

The third analysis of data gives a stable typology on the factorial plane 1×2 (fig. 3) which demonstrates the action of Abate on the structure of the benthic invertebrate populations. A control can be done by the same analysis carried out on the same data identified to a specific level. As an example, we have analysed 111 replicates from Danangoro and Entomokro sites (1978 to 1980). The 21 following taxa have been selected.

EPHEMEROPTERA

Tricorythus sp. 1 .... (E01)
Pseudocloëon bertrandi .... (E21)
Pseudocloëon sp. 1 .... (E29)
Centroptilum sp. 1 .... (E31)
Caenomedea sp .... (E54)
Caenodes sp .... (E57)

DIPTERA

Simulium damnosum s.l. .... (DAM)
Simulium adersi .... (ADE)
Simulium tridens .... (TRI)
Simulium schouledeni .... (SCH)
Antocha sp .... (TIP)
Strictochironomus sp .... (CC5)
Cricotopus quadrifasciatus .... (CO2)
Ablabesmyia pictipes .... (CP1)
Tanytarsus sp .... (CT1)

TRICHOPTERA

Cheumatopsyche falcifera .... (T01)
Cheumatopsyche digitata .... (T10)
Amphipsyche sp .... (T02)
Orthotrichia sp .... (T14)
Chimarra petri .... (T16)
Protomacronema sp .... (T29)

The counts are transformed according to the semi-quantitative scale described above. The factorial plane 1×2 of the analysis is presented in fig. 4 and in this case too, the primary axis is the treatment axis. The analysis of variables which contribute to it will permit the position of certain taxa to become clearer in analyses I, II and III. If the general positions of principal taxa are not modified on the treatment axis, it appears that the central position of SIM (Simuliidae other than *S. damnosum s.l.* results from differences in susceptibilities of the species which represent this taxonomic group. For example *S. schouledeni* is largely favoured by Abate whereas *S. adersi*, a sensitive species, disappears. Only *S. tridens* is effectively unaffected. The same phenomenon can be described for the variable Baetidae, which is slightly negative on axis I in the FCA III. This point is the center of mass of three species; two of them (E31 and E29) are very susceptible and disappear after treatment and one (E21) is unaffected with a very similar reaction to those of Hydropsychidae (PSY). One can note, on the other hand, that all the species of this taxon occupy central positions.

The adoption of a rough level identification conceals therefore certain variations of the faunistic

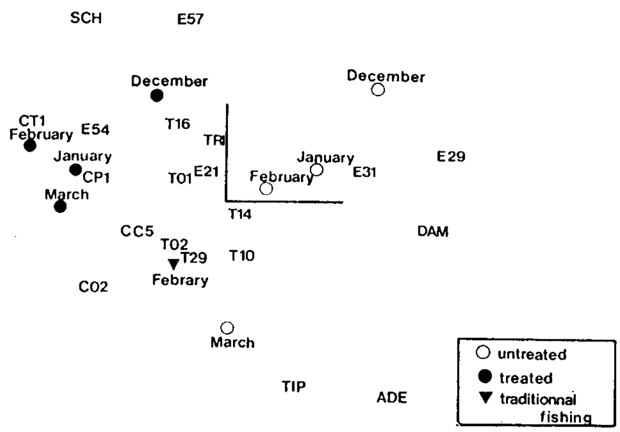

FIG. 4. — Sample collections of Danangoro and Entomokro. Data are classified to a specific level and coded. Factorial plane 1×2

composition. However it does not imply aberrations in the typology. The substitution of one species for another, phenomenon from which the central position of simulidae results, can be considered minor in the global balance-sheet ; all depends on the nature of the "ecological equilibrium" that one expects to safeguard.

3. DISCUSSION

The correspondence analysis demonstrates stable typology allowing the description of variations in structure of the benthic communities from rocky substrates. In the case of raw data, the first axis translates the stability of the ecosystem and axis 2, the susceptibility to temephos. When coded data are used, the factorial plane of axis 1 and 2 remains identical whereas the susceptibility axis does not occupy the same range. The third axis corresponds to seasonal variations in population structure.

The correspondence analysis made on the data classified according to the specific taxonomic level supplied a similar type of information, although of a more precise nature. Axis I corresponds in this case to the axis of pollution by temephos. The projection of the different species on this axis leads to a classification related to the susceptibility of the species to the insecticide.

Thus *S. damnosum* s.l. (DAM) and *Trichorylus sp.* (EO1) are present at one of the extremities of the axis whereas *S. schoutedeni* (SCH) and *Tanylarsus sp.* (CT1) are at the other. The extreme position of *S. damnosum* s.l. on this susceptibility axis explains the success of the Onchocerciasis Control Programme. Amongst the abundant organisms we can define three groups in regard to their susceptibility to Abate treatments under the conditions of the programme. (It means the position of their projection on the axis of susceptibility).

SUSCEPTIBILITY GROUP

Simulium damnosum s.l.	(DAM)
Tricorylhus sp.	(EO1)
Simulium adersi	(ADE)

LESS SUSCEPTIBILITY GROUP

Cheumatopsyche falcifera	(TO1)
Cheumatopsyche digitala	(T10)
Pseudocloëon bertrandi	(E21)

UNAFFECTED GROUP OR TAXA WITH LOW SUSCEPTIBILITY

Stristochironomus sp.	(CC5)
Cricotopus quadrifasciatus	(CO2)
Tanylarsus reductus	(CT1)
Simulium schoutedeni	(SCH)

Now, it has been confirmed that this classification of taxa obtained by FCA is very similar to the scale of relative susceptibility obtained *in situ* with gutter tests. We had obtained in fact, at the time of an experiment *in situ* with temephos (Abate 200 CE):

Tricorythus sp.	87.3 % of detaching
Cheumatopsyche falcifera	14.9 %
Cheumatopsyche digitala	51.6 %
Stictochironomus sp.	35.2 %
Simulium schoutedeni	3.4 %
Cricotopus quadrifasciatus	18.1 %
Tanylarsus s.p.	3.4 %
Simulium adersi	Not tested

The axis of susceptibility to temephos obtained by the factor analysis corresponds therefore to the real sensitivity of the organisms. Lets us recall here that the correspondence analysis comes to this result by taking account not of the numbers but of the relative frequencies, that is to say the structures of the communities.

In the case of coarser taxonomic identification realized in the surveillance programme, we obtained a relative scale of susceptibility similar to that obtained for the species. Only the disappearance of *S. adersi* and the appearance of *S. schoutedeni* are unnoticed because they compensate each other. We note likewise that the disappearance of species of Baetidae is evident.

In these conditions, the analysis performed (FCA) on the surveillance data expresses a tangible reality and the adjustment to an index of pollution (based on coded data) established from the most representative taxa appears to be necessary and suitable. This index would permit a rapid estimation of river pollution by temephos and allow one to control its evolution, efficiently and in a simple way.

4. CONCLUSION

The statistical treatment of the surveillance data by correspondence analysis demonstrates evidence of long term effects of temephos on the rocky substrat invertebrates.

The well known short term effect on populations as it was anticipated, has repercussions on the structure of communities after repeated weekly treatments.

This proof of the long term impact of temephos responds implicity then to the second question formulated at the beginning of this paper. The protocol for surveillance of benthic fauna on rocky substrates provides a sufficiently precise method for pointing out the toxic effect of the insecticide employed in the Onchocerciasis Control Programme during the months of decreasing stream level and at the beginning of the dry season.

If the identification level adopted in the monitoring protocol effectively permits the estimation of a certain action of Abate, the specific identification is necessary to point out substitution of species.

The calculation of the index of pollution based on coded data simplifies and lightens the computations. It allows the reduction of the number of taxa studies, saving time for fundamental research. As a matter of fact, the interpretation of monitoring results cannot be done without first knowing the ecology, susceptibility, voltinism and seasonability of species.

We have in the present work only treated a part of the surveillance data in order to demonstrate:

- the long term effects of Abate;
- the operational value of sampling methods utilized;
- the possibility of demonstrating the effects of temephos by factor analysis.

The treatment of all the collected data in the whole area under surveillance should provide other information on the impact of temephos on non-target fauna.

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