

Onchocerciasis Control Programme in West Africa: a 20-year monitoring of fish assemblages

Didier Paugy ^(a*), Yves Fermon ^(b), Kofi Eddie Abban ^(c), Moussa Elimane Diop ^(d),
Kassoum Traoré ^(e)

^(a) Antenne IRD, MNHN, laboratoire d'ichtyologie, 43, rue Cuvier, 75231 Paris cedex 5, France

^(b) MNHN, laboratoire d'ichtyologie, 43, rue Cuvier, 75231 Paris cedex 5, France

^(c) WRI, P.O. Box M 32, Accra, Ghana

^(d) OCP, BP 237, Kankan, Guinée

^(e) Idessa, BP 633, Bouaké, Côte d'Ivoire

Received July 19, 1999; accepted November 2, 1999

Abstract — Onchocerciasis is a widespread disease in intertropical Africa, which, ultimately, causes irreversible blindness. The disease is transmitted by a small blackfly, *Simulium damnosum* (Diptera), which has aquatic larval and pupal stages. The breeding sites of the blackflies are riffles. These river reaches are the targets of the control campaign of the Onchocerciasis Control Programme in West Africa (OCP). An aquatic monitoring network covering the totality of the area exposed to the insecticide was set up to evaluate environmental impact. In this paper, we present results from the OCP 20-year period of monitoring of the ichthyofauna regularly exposed to larvicides. We do not record any measurable effects of pesticides on the CPUE, abundance of species, trophic structure, community structure or fish health. However, we detect the emergence of a number of medium-term tendencies. These tendencies may relate to climatic conditions that have a consequent effect on hydrology. Thus, we note a constant decrease in the CPUE from the beginning of the monitoring until 1995. The rivers were treated during that time until 1990 or 1993, depending on the station. But even after the treatments ended, the number of catches continued to decrease. As a result, we consider other factors to be the cause of that decline. The average level of annual discharges in this region has been decreasing regularly from the beginning of the 1970s. The production of fish fluctuates in all the rivers according to the flood rate. Important floods inundate larger areas, making greater quantities of food available, and thus improving the conditions for reproduction. The determining factor of the ichthyological stock abundance seems to depend both on the extent and the duration of the flood. In our catches, the observed effect was not immediately evident but appeared a few years later as a cumulative effect of poor hydrological conditions. An increase in the CPUE since 1996 has been related to improved hydrological conditions. In these last few years, we have observed an intensification of the basic flow leading to a ground water renewal. Furthermore, on three of the stations investigated, it appeared that the impediment of rivers (dams) could induce different and/or antagonistic effects. In some cases, we have observed that in spite of unfavourable hydrological conditions, certain species appear to be favoured by the presence of the dam. But, the damming of the river has a negative effect on other species, particularly on the coefficient of condition of migratory fishes. The impact of these factors is enhanced by the fact they exist conjointly. © 1999 Ifremer/Cnrs/Inra/Ird/Cemagref/Éditions scientifiques et médicales Elsevier SAS

Fish assemblage / freshwater environment / insecticides / onchocerciasis / West Africa

Résumé — Programme de lutte contre l'onchocercose en Afrique de l'Ouest : vingt années de surveillance des peuplements ichtyologiques. Maladie largement répandue en Afrique intertropicale l'onchocercose est un fléau qui provoque, à son stade ultime, une cécité irréversible. La maladie est transmise par un petit Diptère, *Simulium damnosum*, qui présente une phase larvaire et nymphale aquatique. Ce sont les gîtes larvaires de ce vecteur, biefs à courant rapide des rivières, que le Programme de lutte contre l'onchocercose en Afrique de l'Ouest (OCP : *Onchocerciasis Control Programme in West Africa*) traite lors de ses campagnes de lutte. Comme toute lutte insecticide, OCP représentait une menace importante pour l'environnement. C'est pourquoi le programme s'est doté d'un réseau de surveillance des écosystèmes aquatiques, couvrant l'ensemble de la zone exposée aux épandages d'insecticides. Ce sont les résultats de vingt années de surveillance de l'ichtyofaune, régulièrement exposée aux traitements larvicides, qui sont présentés ici. Les différentes variables étudiées dans cette étude, ne permettent pas de mettre en évidence un effet décelable des pesticides sur la structure et la richesse spécifique des peuplements. De même, la composition trophique ou la santé des poissons ne semblent pas affectées. Cependant, nous observons parfois certaines tendances, à moyen terme, qui semblent être essentiellement sous l'influence des conditions climatiques, probablement hydrologiques. Ainsi, nous

* Corresponding author: paugy@mnhn.fr

observons une diminution régulière des prises par unité d'effort (PUE) du début de la surveillance jusque vers 1995. Durant cette période, les rivières ont été, selon les stations, traitées jusque 1990 ou 1993. Mais, alors que les traitements étaient terminés, la diminution des captures s'est poursuivie. Nous pouvons donc estimer que d'autres facteurs en sont la cause. Si nous considérons les crues moyennes annuelles et régionales, nous observons une diminution régulière depuis le début des années 1970. Dans toutes les rivières, la production de poisson fluctue en fonction du régime d'inondation. Lorsque les crues sont favorables, elles inondent des superficies plus grandes, ce qui favorise la disponibilité en nourriture, et améliore donc les conditions pour la pérennité des espèces. En fait, le facteur déterminant de la production halieutique semble être lié à la fois à l'étendue et à la durabilité de l'inondation. Dans nos captures, l'effet apparaît avec quelques années de retard comme s'il y avait eu un effet cumulatif des mauvaises conditions hydrologiques. Inversement, l'accroissement des PUE depuis 1996 paraît bien corrélé aux meilleures conditions de crue observées. Ces dernières années, nous notons un renforcement de l'écoulement de base qui se traduit par une recharge des nappes phréatiques. Enfin, sur trois stations étudiées, les barrages peuvent induire différents effets, antagonistes ou non. Dans certains cas, nous observons qu'en dépit de mauvaises conditions hydrologiques, certaines espèces semblent être favorisées par le barrage et sa retenue d'eau. Inversement, le barrage du fleuve peut avoir un effet négatif sur certaines autres espèces, particulièrement sur celles qui effectuent des migrations longitudinales. Tous ces facteurs semblent montrer une pression d'autant plus importante qu'ils se produisent en synergie. © 1999 Ifremer/Cnrs/Inra/Ird/Cemagref/Éditions scientifiques et médicales Elsevier SAS

Peuplement de poissons / eau douce / insecticides / onchocercose / Afrique occidentale

1. INTRODUCTION

Human onchocerciasis, or river blindness, a filaria that causes major public health damage and is a great problem to the economic growth, has been the target of a widespread control campaign that started in the middle of the 1970s in West Africa. Under the auspices of the World Health Organisation (WHO), the Onchocerciasis Control Programme (OCP) was set up in December 1974 on the Volta basin, one of the more seriously affected areas. The control programme was initially planned for a 20-year period, and to include 11 countries comprising an area of 1 300 000 km². The control area initially included 50 000 km of rivers with

about thirty million human residents. At the beginning of the programme, Burkina Faso, the western part of Niger, the northern parts of Benin, Ghana, Côte d'Ivoire, Togo and the south-eastern part of Mali were included (*figure 1*). Treatments started in February 1975 in the central part of the area covered by the OCP, and the programme progressively extended to the south, east and west [10, 29].

1.1. Strategy of larvicide applications

The only possibility to stem the disease transmission was to control the vector, and to avoid a major risk of pollution, it was decided to use pesticides to target the

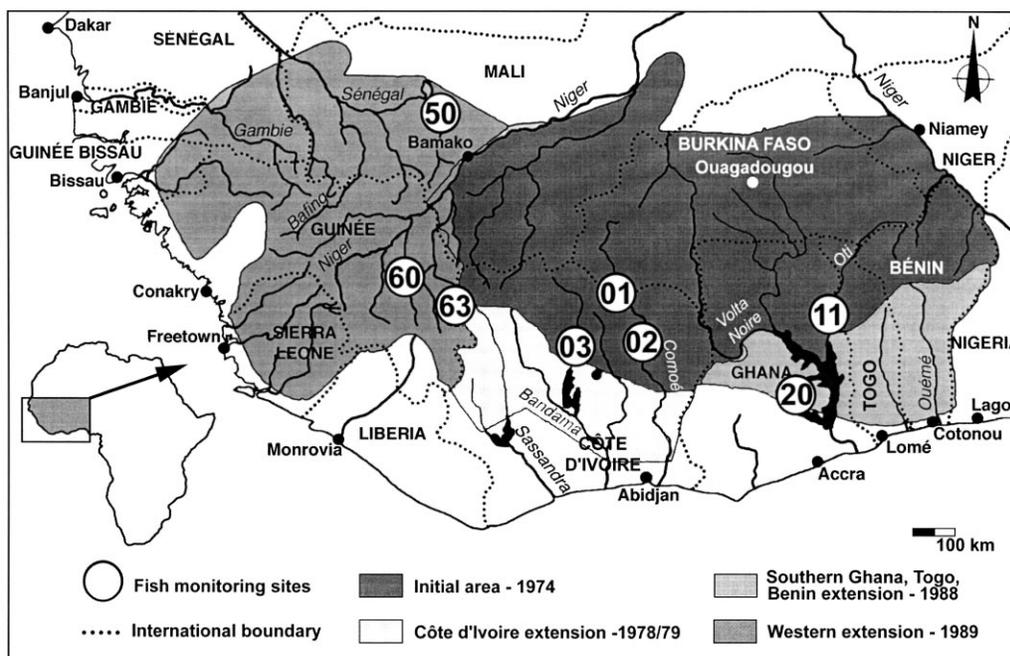


Figure 1. Maximum extension of the Onchocerciasis Control Programme in West Africa and location of the fish monitoring stations.

Table I. Amount (in thousands of litres) of commercialised pesticides used by the OCP.

Year	Temephos organo- phosphate	Chlorphoxim organo- phosphate	B.t. H14 'biological' insecticide	Permethrin pyrethroid	Carbosulfan carbamate	Pyraclofos organo- phosphate	Phoxim organo- phosphate	Etofenprox pyrethroid
1975	76							
1976	130							
1977	156							
1978	216							
1979	263							
1980	185	6	0.5					
1981	130	70	1.5					
1982	163	7	233					
1983	75	36	310					
1984	77	57	257					
1985	130	6	211	3	9			
1986	120	15	385	10	20			
1987	71	30	229	10	8			
1988	84	80	380	26	11			
1989	92	65	275	51	31			
1990	109	34	407	44	36	3		
1991	76		271	46	33	32	21	
1992	47		376	23	27	55	34	
1993	76		209	20	13	45	20	
1994	48		225	29	13	45	20	5
1995	41		237	15	21	38	18	17
1996	28		205	21	6	33	24	14

aquatic larval population living in the fast-flowing parts of the rivers.

At an early stage of the programme, the OCP used a single organophosphorous compound called temephos. Then, the appearance of resistant strains of the vector to temephos necessitated the use of various kinds of pesticides belonging to compounds of several families (table I).

In order to insure optimum efficiency and to avoid any important or even definitive resistant strains, the current strategy of the OCP is complex [11]. First, the sections of rivers where blackflies still occur are the only ones treated. Second, strategies related to the discharge of the rivers are used to promote efficiency (rotation of molecules), and to be cheaper and less hazardous for the environment.

1.2. The environmental monitoring

Insofar as it has been proved that the fish were not really affected by a direct effect of the pesticides in the conditions of the nest control campaign [2], it was decided to monitor the variations in the fish communities in the long term.

The Onchocerciasis Control Programme was probably one of the first long-term pesticide programmes to take into account potential long-term environmental impacts of the pesticides. In order to evaluate the magnitude of the environmental risk, hydrobiologists have used consistent methods and protocols to monitor potential long-term effects of continuous use of larvicides on aquatic populations [4, 8, 18].

Fish monitoring was carried out with standard sets of gillnets of different mesh size. Despite the selective properties of this kind of fishing gear, it was the only method which could be used as a standard by all the teams on the whole OCP area. The following information was recorded: catch per unit effort (CPUE), measured as the quantity of fishes, the communities' structures and the degree of balance between them. For each fish we recorded: weight, length, condition, stomach contents, sex and sexual maturity.

The study we present here follows a synthesis made after 10 years of monitoring of potential long-term effects of the pesticides on the fish fauna [16]. Samples were collected by researchers from IRD-ex Orstom and from the national teams of the participating countries with the financial support of the OCP.

1.3. River hydrology

The OCP area covers a large number of river systems, mostly savannah rivers with a water regime characterised by a flood period from July to November, with a peak in September and a long low water period from December to June. Many of the rivers are intermittent and may totally dry up. For permanent rivers, the discharge is very low during the dry season and the upper course is sometimes reduced to a few pools. Seasonal flood regimes strongly affect the ecology of fish populations [30].

Water discharge shows strong inter-annual variation (figure 2). During the major part of the monitoring period, a long drought occurred, not only in the OCP

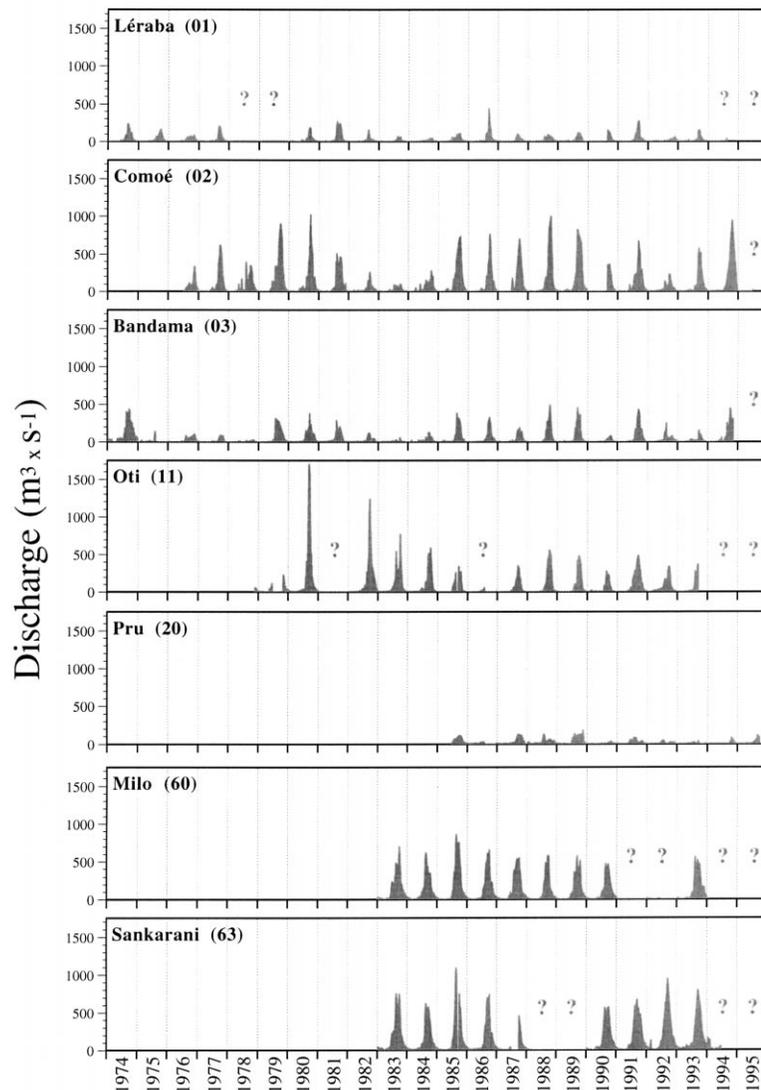


Figure 2. Discharge ($\text{m}^3 \times \text{s}^{-1}$) for the seven monitoring sites of the Onchocerciasis Control Programme (OCP) area.

area, but also in all of West Africa [20]. Such a long drought greatly influences aquatic organisms because, even if the rainy season is normal for a particular year, lack of ground water will induce a very quick decrease of the discharge [23].

2. MATERIALS AND METHODS

2.1. Selection of the stations

Initially, for each country three or four sites were selected both on treated and untreated rivers. But, later the OCP and the Ecological Group requested a decrease in monitoring sites, mostly for economical reasons. Therefore, the number of stations with available sampling data on a significant period was re-

stricted to seven (the eighth one, Baoule (Upper Senegal) in Mali (site 50) was never treated and therefore removed from analysis (figure 1):

- Leraba at boundary bridge (Comoe basin/Côte d'Ivoire), site 01;
- Comoe at Ganse (Comoe basin/Côte d'Ivoire), site 02;
- Bandama at Niakaramandougou (Bandama basin/Côte d'Ivoire), site 03;
- Oti at Sabari (Volta basin/Ghana), site 11;
- Pru at Asubende (Volta basin/Ghana), site 20;
- Milo at Boussoule (Niger basin/Guinea), site 60;
- Sankarani at Mandiana (Niger basin/Guinea), site 63.

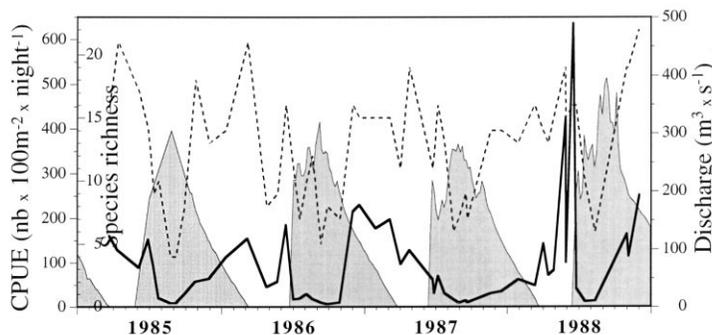


Figure 3. Baoule at Missira (site 50): effect of the flood on CPUE (nb × 100 m⁻² × night⁻¹) and species richness. CPUE: —; species richness: ----; discharge: ■.

2.2. Sampling protocols

According to the protocol established before the experiment was started [18], the sampling was undertaken with a standard set of gillnets of different mesh sizes: 15, 20, 25, 30 and 40 mm (knot to knot distance). Gillnets were used for two consecutive nights, every 3 months.

We first checked that no bias was induced by the different teams’ operational procedure.

The most effective mesh size proved to be 15 mm, then 20 mm. There were many small-sized species and many juveniles of the larger species.

2.3. Variables considered in the analyses

We consider catch per unit effort (CPUE) as the numbers of specimens caught each night for 100 m² of gillnet area. Condition factor (K) was calculated according to the following formula:

$$K = \frac{W}{L^3} \times 10^5$$

where *W* is the weight (g) and *L* the standard length (mm).

Condition is an expression of health and, more generally, the physiological state of the fishes. It may reflect the direct effect of the pesticides on the physiology of the fishes (for example, the impact on reproductive potential) or for indirect effect of pesticides due to an impact on the aquatic invertebrate fauna which is the main feeding source for many species.

To detect community-level change, we calculated the dominance index of Berger-Parker (*d*) [19] and the Shannon diversity index (*I*) calculated using the formula:

$$d = \frac{N_{\max}}{N}$$

$$I = \sum_i^n p_i \times \log p_i$$

where *N*_{max} is the number of individuals of the most abundant species caught, *N* is the total number of specimens, *p*_{*i*} the relative frequency of the species *i* and log *p*_{*i*} its decimal logarithm.

Species richness and CPUE appear to be closely related to the hydrological conditions (figure 3). To reduce the effect of hydrology we have also used the variables described above considering only the sampling dates during the dry season. Dry season months were defined as those months with minimal discharge.

Generally, we have to consider that there is a link between the species richness, the size of the samples [19] and the number of fish caught. In order to avoid this problem, we have calculated the residuals of the regression log SR/log *N* (SR: species richness, *N*: number of fish). Whatever the sites and the season, we could never establish whether a significant decrease or increase in the residual richness exists. In each case, the slope is not significantly different from 0. Furthermore, whether we consider residuals or species richness alone, the general trends are more or less similar.

Finally, to check that the pesticides had not particularly affected any trophic group, the two indices described above were tested on seven well-defined trophic groups [25].

2.4. Analyses carried out

Among the different methods available, we chose to observe an ecological system and its variation throughout and after perturbation [12].

In order to establish the evolution of the structure of the fish assemblages, we carried out correspondence analysis (CoA) on log transformed data [Ln (*x* + 1)] so as to homogenise and normalise the variances. This analysis optimises the variability when dealing with numerous variables (here species are the variables). A first normalised principal component analysis (PCA) was performed considering the overall stations so as to look at the geographical variations. A UPGMA distance analysis was carried out on the factorial coordinates of this PCA to check the intra- and inter-basin relationships. A number of CoA was made taking each station separately on the overall sampling dates

Table II. Shared species ratio: A inter-basins; B inter-sampling sites.

A) Inter basins		n = 225		Comoé	Bandama	Volta	Up. Niger	
	Comoé		100		71.1	38.3	25.9	
	Bandama				100	39.2	25.5	
	Volta					100	44.6	
	Up. Niger						100	

B) Inter-sampling sites		n = 118		ST01	ST02	ST03	ST11	ST20	ST60	ST63
	ST01		100		84.3	78.2	37.9	38.3	39.7	36.8
	ST02				100	71.9	37.9	40.0	36.3	35.2
	ST03					100	33.7	38.3	37.8	35.2
	ST11						100	81.1	55.3	62.5
	ST20							100	56.7	64.1
	ST60								100	74.0
	ST63									100

n: number of samples.

and on the dates of the dry season only. The first four or five axes generally explain more than 50 % of the total variance. So, during the monitoring period, the evolution of these variables will let us know the structure change in fish assemblage.

Concerning the factorial correspondence analysis, we considered for each site only the species with an occurrence of higher than 5 % of the total number of catches. We carried out the same analyses using different trophic levels.

For the coefficient of condition, for each site, we only considered the species for which the number of specimens was, at least, equal to 5. To compare sites, we also considered ecologically similar species of the same genera (e.g. *Schilbe mystus* and *S. mandibularis*).

3. RESULTS

In general, catches were higher during the low water period (from November to June) than during the flood period (from July to October). This relates in part to gillnet efficiency which is lower when comparing sites or years. For that reason, when analysing the data we considered all samples or those taken during the dry season. Indeed, we have noted some differences, but the general pattern is globally the same in the long term. That is why most of the time we considered all together the dry and rainy season samples.

3.1. Species characteristics

The sites were selected in four different basins belonging to two distinct 'ichthyoregions' [13, 27]:

Eburneo-Ghanean zone: Leraba (site 01), Comoé (site 02) and Bandama (site 03);

Sahelo-Sudanian zone: Oti (site 11), Pru (site 20) and Niger (sites 60 and 63).

The climates of the different regions are quite similar, but the fish fauna from each is quite distinct

(table II) and it is necessary to consider each sampling site separately. Although we observed differences between each station, the same 27 species were caught in all the rivers. Nevertheless, most of the species were caught at few sites only and 20 species were caught only at one site.

The numerically dominant species in the rivers of the Côte d'Ivoire was *Alestes baremoze*, and to a lesser degree *Schilbe intermedius*, which lives mainly in the Comoé basin (sites 01 and 02). The dominant species in the Oti (site 11) was *Schilbe mystus*, but many other species might sometimes co-dominate such as *Brycinus* spp. and *Synodontis schall*. In the Pru river (site 20), which is a small tributary of the Volta basin, *Schilbe intermedius* was the dominant species, but *Brycinus* spp. and *Schilbe mystus* were also very abundant. In the Upper Niger basin, the situation is quite different according to the various sites. At Boussoule (site 60), mormyrids were very numerous as were *Brycinus* spp. and *Schilbe intermedius*. The situation was very different at Mandiana (site 63) where *Brycinus leuciscus* was the dominant species but *Schilbe mystus* and *Chrysichthys auratus* were occasionally also abundant. Each site obviously has a fairly different configuration. For example, the Milo, in the region of Boussoule-Kankan, is a rocky river, which is a good biotope for mormyrids. Conversely, the Sankarani near Mandiana, is a large and sandy river just at the mouth of the Selingue dam, which is favourable to pelagic species such as *B. leuciscus*.

For most species, seasonal and annual changes in abundance follow the fluctuations of total catches. Among frequent species we have not noted serious decline, except for two species of Mormyridae, *Hippopotamyrus pictus* which disappeared from the Milo river (site 60) since mid 1992, and *Marcusenius ussheri*, which became very scarce in 1990–1991 in the sites of the Côte d'Ivoire, but reappeared later in the years 1995–1996.

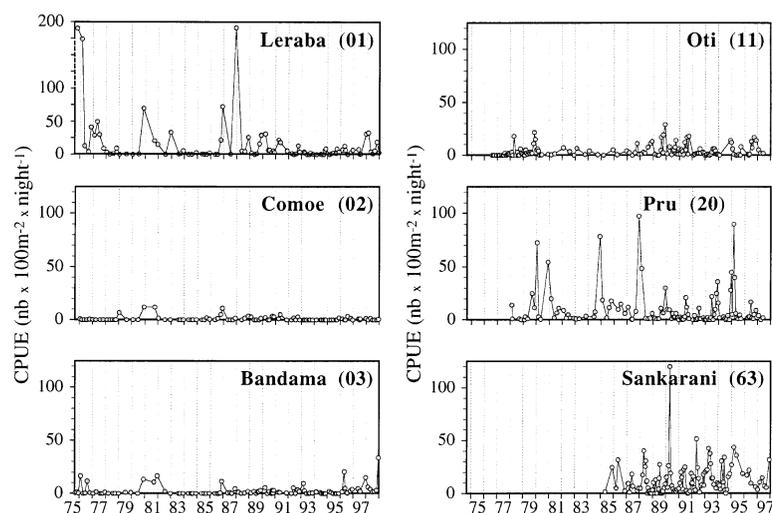


Figure 4. *Schilbe intermedius* (Schilbeidae): changes in CPUE (nb \times 100 m⁻² \times night⁻¹) in six monitoring sites sampled with gillnets.

The case of *Schilbe intermedius* in the rivers of Côte d'Ivoire is distinct and deserves an explanation. There were cycles of 1–3 years during which we did not catch any member of that species. We initially attributed this disappearance to insecticides but as specimens became abundant again in spite of the continuous spraying of larvicides, the phenomenon appeared to be independent of insecticide applications. The absence of the species does not seem to be linked to any particular hydrological event. This should suggest that some natural fluctuations exist, but in the present state of our knowledge they are impossible to link with any precise external event [17]. The above phenomenon observed in the Côte d'Ivoire was not found in the Volta and Niger basins, where the catches were always more or less constant during the study (figure 4).

3.2. Species richness

In the Leraba (site 01) and the Comoe (site 02) rivers (figure 5), there was a decline in species richness until 1992–1993 (less than half of the species that were observed at the end of the 1970s), followed by an increase.

The situation was similar for the third station of the Côte d'Ivoire (site 03). The recovery started in 1995 and the values we observed in 1996–1997 are identical to those observed at the beginning of the study.

On the Volta basin, the situation differs between sites. On the Pru river (site 20), the species richness was lower during the early 1980s than after the first treatments (in 1985). However, since the early 1990s, there has been a regular decrease in species richness. Species richness in the Oti river station (site 11) was variable but with no obvious trends (see residuals figure 5).

In the Niger basin, both stations (sites 60 and 63) have shown an increase in species richness whether we take into account all samples or only dry season samples (figure 5).

To assess whether variation in CPUE and species richness were synchronised among sites, we carried out a PCA (principal component analysis on log transformed data [$\ln(x + 1)$] of the dry season) between 1988 and 1993. We only took into account the 20 most representative species for each station. As expected, stations in Côte d'Ivoire were more similar than between the stations of Côte d'Ivoire and others regions, even if these sites belong to the same basin (figure 6). This result shows that the correlation between geographical and/or climatic phenomena is higher than a possible impact of insecticides.

3.3. Experimental catches

At the Côte d'Ivoire stations, CPUE decreased until 1991 or 1993, after which time the number of catches in the three sites showed a clear rising trend (figure 7). The treatments on the Leraba river (site 01) stopped in 1989. They stopped later (1993) on the two other rivers (sites 02 and 03). It is worth noting that the catches started rising again in 1995 in the three situations, after the end of the spraying operations. However, if the recovery of the number of catches occurred the same year, even through all the treatments did not end at the same time on the stations. These observations do not allow us to dismiss the idea of a possible effect of larvicides, but as the number of catches increased synchronously it is plausible that the improved situation is linked to better ecological conditions, as a result of improved hydrology and climate.

On the Pru river (site 20), CPUE seems to have been rising slightly from 1996 onwards. Trends in CPUE on

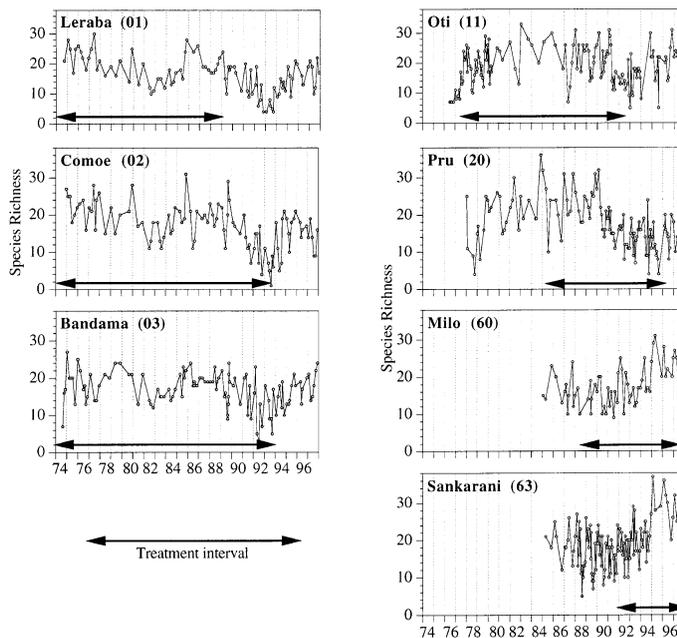


Figure 5. Changes in species richness per samples for the whole set of gillnets.

the Oti river (site 11) are not evident. In this case, there may be an influence of the Volta lake which acted as a buffer against the flood that occurred in the region. In the case of the Pru river, the lake would play a smaller part because of the smaller size of the river.

Generally speaking, the conditions in the Niger basin are good. In the Milo river the CPUE were stable until 1994 and then increased. At the Sankarani river, catches varied strongly with hydrological conditions. However, if we only consider the results of the dry season, no real decrease was observed (figure 7).

3.4. Structure of the fish catches

3.4.1. Correspondence analysis

In order to compare samples as well as species, the factorial analysis of correspondence (CoA) for which

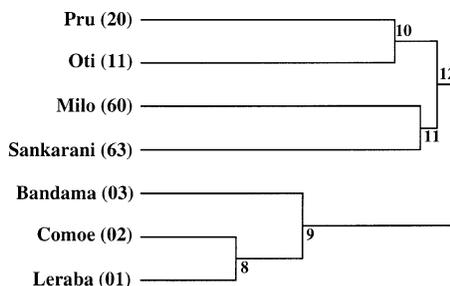


Figure 6. Hierarchical classification (average link on Euclidian distance) of the centre of mass of the factorial co-ordinates (PCA) of the sampling dates for each site.

salient points have been described elsewhere [3, 15] was used. We used the software ‘ADE-4’ [5] for the whole analysis.

Similarly to what can be seen for the species abundance and the CPUE, seasonal variations in the structure of catches are evident.

To illustrate the main results, three examples are considered, one for each region. A smooth change of structure in relation to first axis in the Côte d’Ivoire, particularly since 1989, is evident on the Bandama river (site 03) (figure 8). The diagram is approximately the same whether all the samples or only the dry season data are considered. The change in structure occurs especially in the case of rare species such as *Barbus macrops*, *Hemichromis bimaculatus* or *Raia-mas senegalensis* which disappeared from the samples taken recently. Nevertheless, considering the most dominant species, there is a decrease in the total number of catches, concerning particularly *Alestes baremoze*, even if that species was clearly dominant in 1974–1976, it no longer dominates the catches to the detriment of others. In terms of abundance of species, the values are more or less the same, because only a few species are concerned. However, in terms of catches, because these species represented more or less 50 % of the total catches, the decrease in the CPUE is considerably influenced. The balance is different whether it is the abundance of species or the CPUE. It is unlikely that the situation has improved under the influence of insecticides, we can think for several reasons that we are facing a natural phenomenon. Following the perturbations due to different human impacts on the Bandama river (Kossou and Ferkesse-

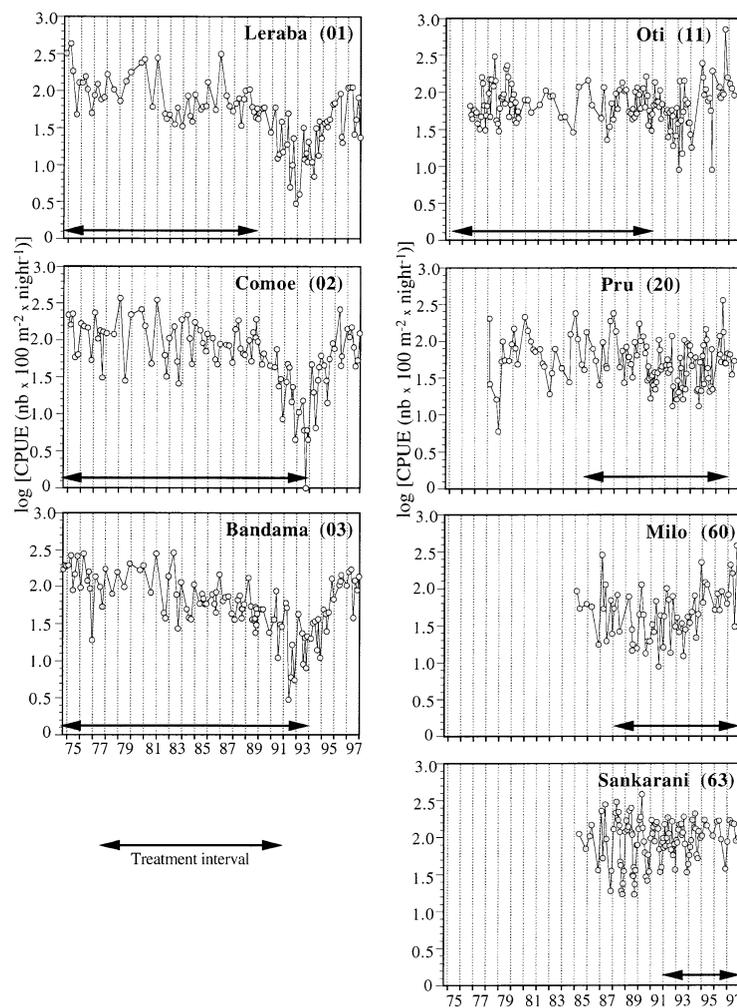


Figure 7. Changes in total CPUE ($\text{nb} \times 100 \text{ m}^{-2} \times \text{night}^{-1}$) in the seven monitoring sites sampled with gillnets.

dougou dams), it is likely that the system has attained a new improved equilibrium.

Our results suggest a slight, but regular change in the structure of catches in the Pru river. Some rare species such as *Heterotis niloticus*, *Mormyrus macrophthalmus*, *Gymnarchus niloticus*, *Clarias anguil-laris* and *Auchenoglanis occidentalis* have completely disappeared from the catches. Conversely, species such as *Barbus macrops*, *Schilbe mystus*, *Siluranodon auritus* and *Synodontis violaceus* have started to appear or become more abundant since the beginning of 1990s onwards.

Concerning the Sankarani river (site 63) (figure 9), the first axis clearly separates the samples of the dry and the rainy seasons. More precisely, considering only the samples of dry season, there is a clear distinction between the samples taken in May and in June, and those of the other months. The rainy season samples are characterised by the presence of *Parailia pellucida*, a small Schilbeidae (i.e. *S. mystus* and

S. intermedius), which has to migrate upstream from the lake during the flood to reach its breeding sites. This species does not accomplish as long a migration as do large schilbeids such as *Schilbe* [22]. The catches in May–June are dominated by the presence of *Schilbe mystus* which start their anadromous migration and leave the lake. At the end of the dry season and during the rainy season, the catches are characterised by the presence of three species of *Petrocephalus* (*P. bovei*, *P. sudanensis* and *P. ansorgii*). Apparently, in man-made lakes, migrations of mormyrids to the river mouths can occur several months before the flood starts [22].

3.4.2. Shannon diversity and evenness indexes

The dominant species in Côte d’Ivoire was *Alestes baremoze* and it was associated with *Schilbe intermedius* or *S. mandibularis* (table III). These species were dominant in more than 50 % of the catches. Since the monitoring started, the diversity has been relatively

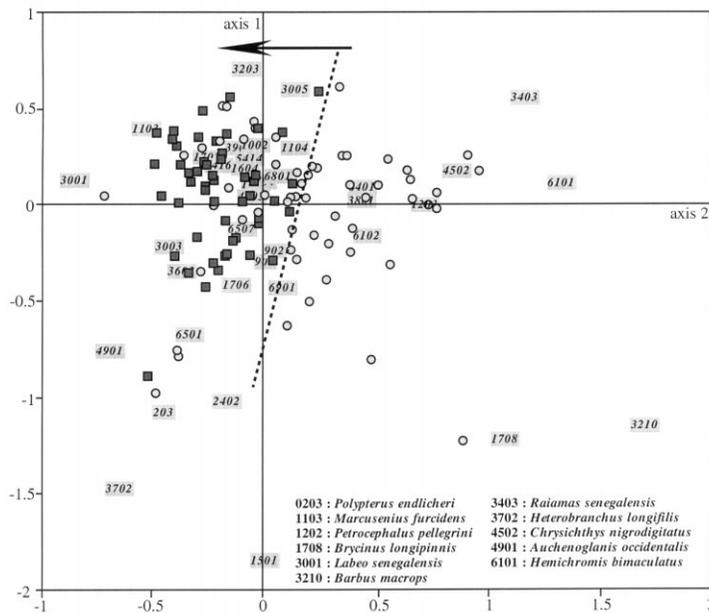


Figure 8. Bandama River (site 03): factorial plan I and II of the correspondence analysis (samples and species projection). Species listed are those which have an important contribution (axis 1) in the performed analysis (taxonomic classification). 1975–1988: ●; 1989–1997: ■.

stable. However, events (1982–1984 and 1992–1994) sometimes lead to a decrease in diversity. In all of the cases, these events are related to a strong dominance of the species named before, mainly *Alestes baremoze*.

The structure and the diversity have not changed but these two or three species are ‘naturally’ dominant in the catches. The abundance of species and the total CPUE parameters confirm these observations.

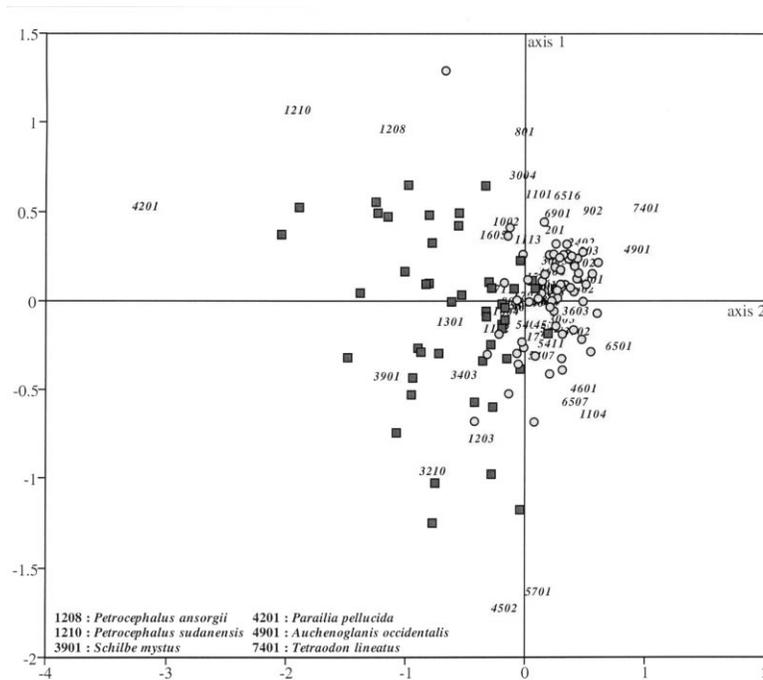


Figure 9. Sankarani (site 63): factorial plan I and II of the correspondence analysis (samples and species projection). Species listed are those which have an important contribution (axis 1) in the performed analysis (taxonomic classification). Dry season: ●; rainy season: ■.

Table III. Dominance frequencies of the species in the seven monitoring sites for all the catches (AS) and for the dry season (DS) catches only.

Species	Site 01		Site 02		Site 03		Site 11		Site 20		Site 60		Site 63	
	AS	DS												
<i>Polypterus senegalus</i>									5.0	4.3				
<i>Polypterus endlicheri</i>	1.1	2.3												
<i>Mormyrus hasselquistii</i>			1.0	2.1										
<i>Hippopotamyrus pictus</i>											3.2	2.6		
<i>Marcusenius senegalensis</i>							1.4	2.5	2.5	4.3				
<i>Marcusenius cyprinoides</i>							0.7	1.3						
<i>Marcusenius ussheri</i>	1.1													
<i>Marcusenius mento</i>											1.6	2.6	1.8	1.6
<i>Petrocephalus bane</i>							2.2	2.5						
<i>Petrocephalus bovei</i>	2.1	4.5	5.1	10.6	3.6	6.4	2.2		1.7	2.9	7.9	7.7	0.9	1.6
<i>Petrocephalus ansorgii</i>											11.1	7.7		
<i>Petrocephalus pallidomaculatus</i>							2.2		4.1	2.9	6.3	10.3		
<i>Petrocephalus soudanensis</i>											4.8	5.1	1.8	
<i>Hippopotamyrus psittacus</i>											4.8	7.7		
<i>Pollimyrus isidori</i>									0.8					
<i>Hepsetus odoe</i>									3.3	4.3				
<i>Hydrocynus forskalii</i>					1.8	2.1								
<i>Hydrocynus vittatus</i>							1.4	1.3						
<i>Alestes baremoze</i>	34.0	29.5	39.8	34.0	49.1	42.6								
<i>Brycinus macrolepidotus</i>	2.1	2.3	2.0	2.1	7.3	10.6	1.4	2.5	5.8	8.7	17.5	23.1	8.0	11.1
<i>Brycinus imberi</i>	2.1	4.5	4.1	6.4										
<i>Brycinus nurse</i>	3.2	4.5	4.1	4.3	18.2	21.3	7.9	13.8	9.9	15.9	7.9		1.8	3.2
<i>Brycinus leuciscus</i>							18.0	21.3	5.0	2.9	7.9	10.3	31.3	25.4
<i>Distichodus rostratus</i>							0.7	1.3	5.8	7.2				
<i>Distichodus engycephalus</i>													1.8	1.6
<i>Labeo senegalensis</i>							10.1	13.8						
<i>Labeo coubie</i>							2.2	3.8						
<i>Labeo parvus</i>									3.3	4.3				
<i>Schilbe intermedius</i>	28.7	29.5			2.7	4.3	2.9	2.5	17.4	11.6	11.1	2.6	13.4	15.9
<i>Schilbe mystus</i>							26.6	13.8	15.7	4.3	1.6		16.1	3.2
<i>Schilbe mandibularis</i>	10.6	2.3	25.5	23.4	9.1	4.3								
<i>Chrysichthys auratus</i>							0.7	1.3			9.5	15.4	18.8	30.2
<i>Chrysichthys nigromarginatus</i>			5.1	10.6	0.9	2.1	2.9	2.5					0.9	
<i>Chrysichthys maurus</i>	5.3	6.8	8.2	2.1	0.9									
<i>Synodontis sorex</i>							1.4	1.3						
<i>Synodontis eupterus</i>							0.7		2.5	2.9				
<i>Synodontis filamentosus</i>							2.2	3.8	1.7	2.9	1.6		2.7	4.8
<i>Synodontis violaceus</i>							0.7	1.3						
<i>Synodontis ocellifer</i>							3.6	3.8	0.8	1.4				
<i>Synodontis velifer</i>							1.4	1.3	1.7	1.4				
<i>Synodontis schall</i>	5.3	6.8			3.6	2.1	4.3	2.5	8.3	11.6				
<i>Synodontis bastiani</i>			1.0	2.1										
<i>Synodontis comoensis</i>	1.1	2.3	3.1	2.1										
<i>Hemichromis fasciatus</i>							0.7	1.3	0.8					
<i>Chromidotilapia guntheri</i>	2.1	4.5			1.8	4.3			4.1	5.8			0.9	1.6
<i>Sarotherodon galilaeus</i>					0.9									
<i>Tilapia zillii</i>			1.0				0.7	1.3						
<i>Lates niloticus</i>	1.1						0.7				3.2	5.1		

The catches in the Volta basin rivers are generally diverse but, sometimes, species such as *Brycinus nurse*, *B. leuciscus*, *Labeo senegalensis* and *Schilbe*

mystus are particularly abundant. The case of the Pru river (site 20) requires few comments. The catches were more diverse between 1983 and 1992. The

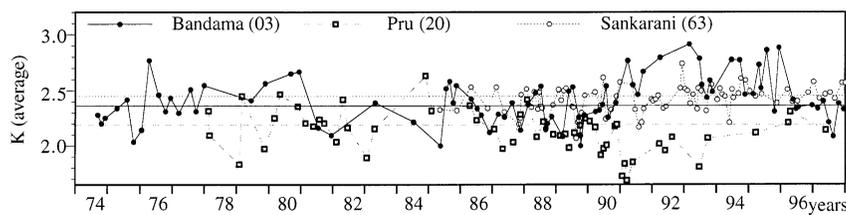


Figure 10. *Brycinus nurse* (Characidae): changes in coefficient of condition (K) for selected stations.

abundant species were less influent and, at the same time, a notable increase in the abundance of species occurred, mainly during the dry season. That period corresponds to a favourable hydrological balance. Because of the shape of the Pru (a small tributary of 6 500 km²), we consider that the good flood conditions favoured the resettlement by species which remain scarce when the field conditions are less favourable. In that way, the Lake Volta played the role of a sanctuary when favourable conditions enabled its re-colonisation by a type of fauna close to that of the lake. For example, there is a decrease in the catches of species which are characteristic of small tributaries (e.g. *Polypterus senegalus*, *Hepsetus odoe* and *Hemichromis fasciatus*). On the contrary, the number of *Siluranaodon auritus*, *Schilbe mystus* and *Synodontis violaceus*, which are characteristic of large rivers, increased in the catches of the Pru river.

There is not much change in the index of diversity for the Niger basin. If *Brycinus leuciscus* is still dominant in the Sankarani (site 63), it is now often supplanted by *Schilbe intermedius*. This result is confirmed by the value of the evenness which has been higher since 1994. The bloom of the catches of *B. leuciscus* is likely to have been a consequence of the filling of the dam of Selingue. The fact that lower catches are returning is certainly the sign of a smooth equilibrium of the communities.

3.5. Condition factor

All results of the condition factor listed were calculated and interpreted for each single species and for each site. Condition factor can account for the direct effect of the pesticides on the physiology of the fishes (for example, the impact on the reproductive potential) or for indirect effects through an impact on the invertebrate fauna which is the main feeding source for many species. In order to analyse these possible effects, we selected species answering three criteria: abundance, strategies of reproduction and diet.

Considering all the populations of a species, a clear cycle of the condition factor according to the month or the season is not evident. Nevertheless, literature on the subject is full of data concerning the evolution of K according to the season. This depends mostly on the maturation of the gonads [1], but in a global analysis as is performed here where the average of the condi-

tion factors according to the month are calculated, the inter-annual variations seem to override any seasonal cycle.

On the contrary, in most cases, the average condition is linked to geography. That way, taking an ubiquitous species such as *Brycinus nurse*, nearly all the fish of the Volta basin have a lower condition than those of the Niger river or of the rivers of Côte d'Ivoire (figure 10). Further more, species of the Sahelo-Sudanian group such as *Schilbe mystus* (formerly *Schilbe niloticus* = *Eutropius niloticus*) have a lower condition factor in the Volta than in the Niger basin. In general, the condition of the fish from the Oti river is less than that of the fish of the Pru river (figure 11). For the fish of Côte d'Ivoire alone, in most cases the K of the fish of the Leraba river is better than that of the fish of the other rivers.

Whatever the stations and whatever the species and their trophic group (insectivorous, carnivorous, omnivorous, etc.), the selected examples show that the values of the coefficient of condition are relatively irregular and fluctuate around an average. This does not appear to have been altered since the beginning of the treatments, except possibly for *Schilbe mystus* in the Oti (figure 11) and Black Volta (not in our analysis) rivers. In these two sites, the decrease in K for *S. mystus* more or less follows the introduction of treatments with permethrin and carbosulfan. These two drastic larvicides were not required that much in the Pru river where there was no decrease in K apart from the short period 1989–1990. So, although we are not able to demonstrate that there is an absolute correlation between the decrease in K in Oti (and Black Volta) and the application of toxic larvicides, we cannot dismiss the idea of a temporary effect of the insecticides on the condition of the fishes.

Other short-term effects were observed and seem to be independent of the insecticide spraying. For example, the condition of *Alestes baremoze* or *Schilbe mandibularis* which was initially low or medium in the same site eventually increased (figure 12). The low K values observed for these species at this site, beyond strict poor hydrological conditions, is probably due to the fact that this site is situated between two large dams (Kossou and Ferkessedougou). The harnessing of that river and the regulation of the flood must be a serious constraint for migratory species such as *A. baremoze* and *S. mandibularis*. The drop in K

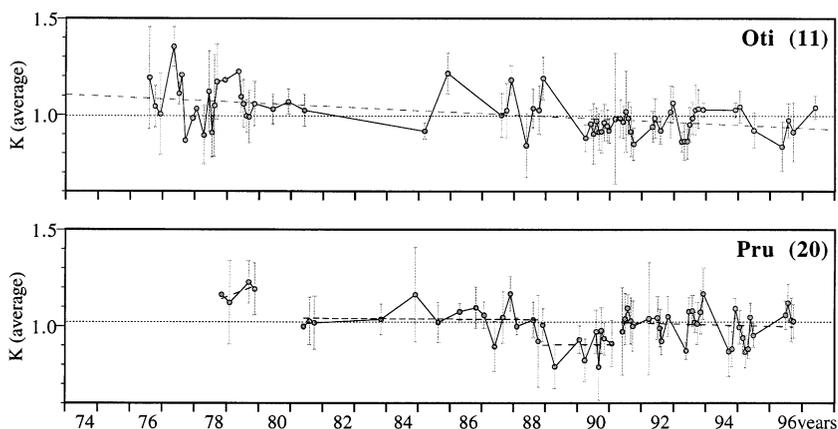


Figure 11. *Schilbe mystus* (Schilbeidae): changes in coefficient of condition (K) for the selected stations.

during the period 1976–1977 for *A. baremoze* was restricted to the course of the Bandama river situated between Kossou and Ferkessedougou. Below the Kossou dam and upstream from the Ferkessedougou dam, fishes show normal condition [24]. As the entire course of the Bandama was treated, it would appear that the decrease in condition is not due to the spraying of insecticide. These examples suggested that the effects of a single perturbation (dams) can interact with and multiply the consequences of other disturbances (low flood), with a cumulative impact on the ecosystem [9].

4. CONCLUSION

The species considered in this study reach maturation at the end of their first year and they rarely live more than 4 or 5 years [1, 21].

Therefore, for all the sites, the catches do not give more information concerning long-term variations,

whether analysed as a whole or by trophic group (see above). Evidently, no trophic association, particularly the insectivorous group for which the main feeding item might be reduced by the treatments, seems to have been affected during the monitoring period. This compares favourably with other experiments carried out in other areas. For example, in the Victoria Nile (Uganda), the control of blackflies with the use of DDT induced a drastic change in the feeding resources of some of the species such as Mormyridae or a drastic lack of food for other species such as *Aethiomastacembelus frenatus* [6, 7].

The relative stability of the condition factor for each species indicates that their feeding was not unduly interrupted. Two hypotheses can be proposed. Either feeding sources are always available, or the fishes are able to change their feeding habits as has been demonstrated for other untreated rivers of the region [25]. Whatever explanation applies the fish do not seem to be affected biologically nor physiologically by

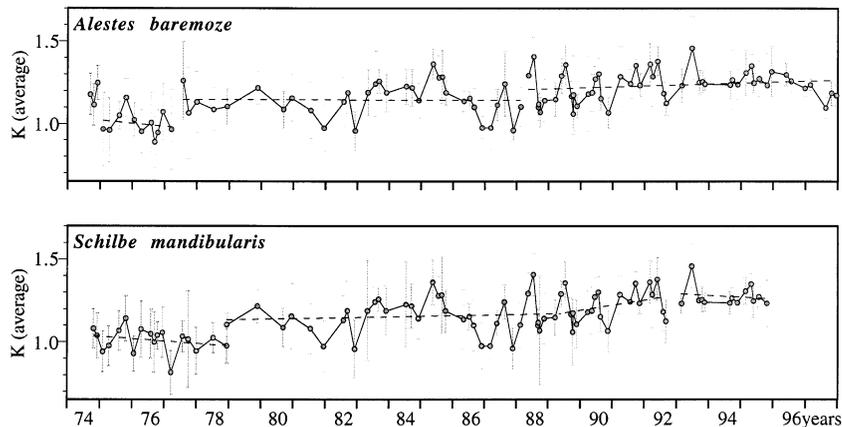


Figure 12. Bandama (site 03): changes in coefficient of condition (K) for the selected migratory species.

larvicides [2]. That also indicates that the insecticides used do not have any detectable toxicity on the metabolism of species [28].

Considering the different variables used in this study, we did not find any detectable effects of pesticides on the CPUE, the abundance of species, as well as on the community and trophic structure and the fish health (condition factor and reproduction strategies). However, we noticed a number of trends which appear to be related mainly to climatic conditions, probably to hydrology. Thus, there was a regular decrease in CPUE from the beginning of the monitoring until 1995. The rivers were treated during that time until 1990 or 1993, depending on the stations (*figure 7*). The decrease persisted even after the treatments ended. As a result, we consider other factors to be the cause of that process. The average level of annual discharge in that region has been decreasing regularly

from the beginning of the 1970s (*figure 13*). A recent study (Huguéy, pers. comm.) showed that there was a correlation between discharge and CPUE during the first 10 years of monitoring (year^{-1}). The production of fish fluctuates in all the rivers according to the flood rate. Important floods inundate larger areas, making greater quantities of food available, and improving the conditions for reproduction [30]. In the central delta of the Niger (Mali), plots of annual catches and loss of water are highly correlated. The determinant factor of the ichthyological stock abundance appears to depend on the extent and durability of the flood. In fact, 69 % of fish under 1 year old are caught in nets of mesh sizes smaller or equal to 20 mm [14]. Those observations agree closely with our own observations. In our catches, the observed effect was not immediately clear but appeared a few years later as a cumulative effect of poor hydrological conditions. Conversely, the increase

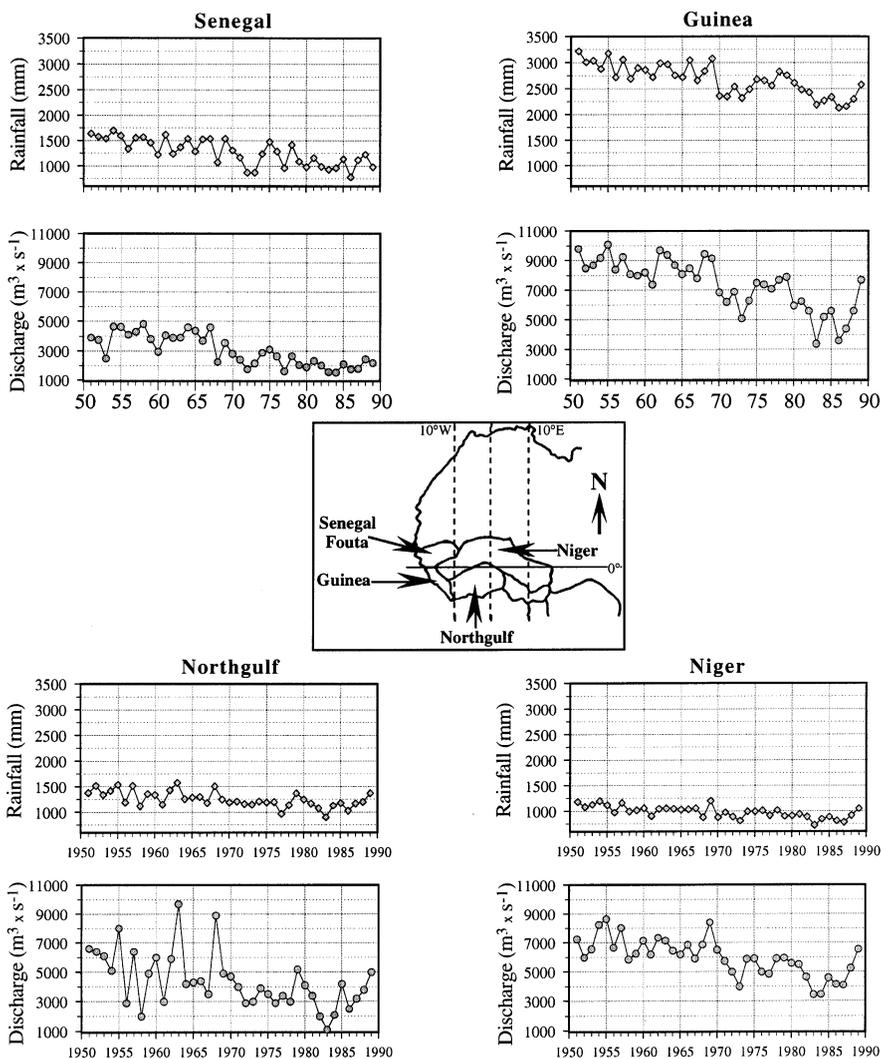


Figure 13. Average annual and regional discharge ($\text{m}^3 \times \text{s}^{-1}$) and rainfall (mm) in four regions of West Africa (after Mahé, 1993).

in the CPUE since 1996 has been related to better hydrological conditions (IRD, France, Hydrological Service, Internet data). In these latter years, there has been an intensification of the basic flow leading to a ground water renewal, although that phenomenon remains quite clearly smooth if we consider the whole basin (Sircoulon, pers. comm.).

Furthermore, for three of the stations investigated, it appeared that the hindrance of rivers (dams) induced different and/or antagonistic effects. In certain cases, notwithstanding poor hydrological conditions, some of the species were favoured by the presence of the dam. For example, in the Sankarani river just upstream from the Selingue lake, a bloom of pelagic species such as *Parailia pellucida* was recorded because of lacustrine conditions. At the same time, the condition factors of predators such as *Hydrocynus* spp. increased significantly. In a similar way, Lake Volta acted as a buffer for the rivers of the Ghanaian region under poor hydrological conditions. Conversely, the damming of the river also has a negative effect on some species, particularly on the coefficient of condition of migratory fishes.

When compared with the results obtained after the first 10 years of monitoring [16], the fish structure has

not changed and we can conclude that the pesticides sprayed by the OCP do not influence the structure of the main fish community, the species richness nor the fish biology. Finally, we record that no fish species has disappeared entirely. The influence of long-term monitoring must be considered before we interpret the results. Thus, climatic changes, which generally have a great influence on the population dynamics of fishes, need to be considered. This is why we have to understand and remove the natural fluctuations of species from the situation. In a short-term study, we could have ended up with the wrong conclusions, because natural fluctuations do occur and species (*Schilbe intermedius*, for example) can temporarily disappear.

Another important aspect is to evaluate the results in terms of the investment made. Apart from the results concerning the use of larvicides, the monitoring generated an important understanding of fish biodiversity [26]. We conclude that the OCP was a very successful control programme because, not only did it not have any drastic effect on the fauna, but we also know now that it prevented three million of children from going blind [29].

Acknowledgements

The World Health Organisation (WHO) Onchocerciasis Control Programme (OCP) has given the main part of the financial support for this environmental aquatic monitoring. We are very grateful to B. Hugueny and C. Lévêque (IRD, Paris), T. Oberdorff (Laboratory of Ichthyology, MNHN, Paris), P.H. Skelton (J.L.B. Smith Institute, Grahamstown) and L. Yaméogo (OCP, Ouagadougou) for commenting and giving valuable suggestions that improved the drafts of the manuscript.

REFERENCES

- [1] Albaret J.-J., Reproduction et fécondité des poissons d'eau douce de Côte d'Ivoire, Rev. Hydrobiol. Trop. 15 (1982) 347–371.
- [2] Antwy L.A.K., Effects of aerial spraying of chlorophoxim on the brain acetylcholinesterase activity of the fish from three rivers in the Côte d'Ivoire, West Africa, Environ. Pollut. 39 (1985) 151–159.
- [3] Benzecri J.-P., L'analyse des données. I : La taxonomie. II : L'analyse des correspondances, Dunod, Paris, 1973.
- [4] Calamari D., Yaméogo L., Hougard J.-M., Lévêque C., Environmental assessment of larvicide use in the Onchocerciasis Control Programme, Parasitol. Today 14 (1998) 485–489.
- [5] Chessel D., Dolédec S., Thioulouse J., ADE: HyperCard© Stacks and Programme Library for the Analysis of Environmental Data, URA CNRS 1451, Univ. Lyon 1, Lyon, France, 1995.
- [6] Corbet P.S., Effects of *Simulium* control on insectivorous fishes, Nature 181 (1958) 570–571.
- [7] Corbet P.S., Some effects of DDT on the fauna of the Victoria Nile, Rev. Zool. Bot. Afr. 57 (1958) 73–95.
- [8] Crosa G., Yaméogo L., Calamari D., Hougard J.-M., Long term quantitative ecological assessment of insecticides treatments in four African rivers: a methodological approach, Chemosphere 37 (1998) 2847–2858.
- [9] Fiedler P.L., Jaïne S.K., Conservation Biology. The Theory and Practice of Nature Conservation, Preservation and Management, Chapman & Hall, London, 1992.
- [10] Hougard J.-M., Poudiougou P., Guillet P., Back C., Akpoboua L.K.B., Quillévé D., Criteria for selection of larvicides by the Onchocerciasis Control Programme in West Africa, Ann. Trop. Med. Parasitol. 87 (1993) 435–442.
- [11] Hougard J.-M., Yaméogo L., Sékétéli A., Boatin B., Dadzie K.Y., Twenty-two years of blackfly control in the Onchocerciasis Control Programme in West Africa, Parasitol. Today 13 (1997) 425–431.
- [12] Hugueny B., Fish monitoring data analysis, OCP/VCU/HYBIO/92. 4, 1992.

- [13] Huguény B., Lévêque C., Freshwater fish zoogeography in west Africa: faunal similarities between river basins, *Environ. Biol. Fishes* 39 (1994) 365–380.
- [14] Laë R., Influence de l'hydrologie sur l'évolution des pêcheries du delta central du Niger, de 1966 à 1989, *Aquat. Living Resour.* 5 (1992) 115–126.
- [15] Legendre L., Legendre P., *Écologie numérique*, 2^e ed., vol. 1–2, Masson, Paris, 1984.
- [16] Lévêque C., Fairhurst C., Abban K., Paugy D., Curtis M.S., Onchocerciasis Control Programme in West Africa: ten years monitoring of fish populations, *Chemosphere* 17 (1988) 421–440.
- [17] Lévêque C., Herbinet P., Caractères méristiques et biologie de *Schilbe mystus* (Pisces, Schilbeidae) en Côte d'Ivoire, *Cah. ORSTOM, sér. Hydrobiol.* 13 (1979) 161–170.
- [18] Lévêque C., Odei M., Pugh Thomas M., The Onchocerciasis Control Programme and the monitoring of its effects on riverine biology of the Volta River Basin, in: Perring F.H., Melanby K. (Eds.), *Ecological Effects of Pesticides*, Linnean Soc. Symp., ser. 5, 1979, pp. 133–143.
- [19] Magurran A.E., *Ecological Diversity and its Measurement*, Croom Helm, London, 1992.
- [20] Mahé G., Les écoulements fluviaux sur la façade atlantique de l'Afrique. Étude des éléments du bilan hydrique et variabilité interannuelle, analyse de situations hydroclimatiques moyennes et extrêmes, Orstom, études & thèses, Paris, 1993.
- [21] Mérona de B., Modèle d'estimation rapide de la croissance des poissons d'eau douce d'Afrique, *Rev. Hydrobiol. Trop.* 16 (1983) 103–113.
- [22] Munro A.D., Tropical freshwater fish, in: Munro A.D., Scott A.P., Lam T.J. (Eds.), *Reproductive Seasonality in Teleosts: Environmental Influences*, CRC Press, Boca Raton, Florida, 1990, pp. 145–239.
- [23] Olivry J.-C., Bricquet J.-P., Mahé G., Vers un appauvrissement durable des ressources en eau de l'Afrique humide ?, in: Gladwelle J.L. (Ed.), *Hydrology of warm humid regions*, Proc. Yokohama Symp., July 1993, IAHS Publ. 216, 1993, pp. 67–78.
- [24] Paugy D., Écologie et biologie des *Alestes baremoze* (Pisces, Characidae) des rivières de Côte d'Ivoire, *Cah. Orstom, sér. Hydrobiol.* 12 (1978) 245–275.
- [25] Paugy D., Écologie des poissons tropicaux d'un cours d'eau temporaire (Baoulé, haut bassin du Sénégal au Mali) : adaptation au milieu et plasticité alimentaire, *Rev. Hydrobiol. Trop.* 27 (1994) 157–172.
- [26] Paugy D., Elouard J.-M., Recherches hydrobiologiques Orstom réalisées dans le cadre du programme de lutte contre l'onchocercose : bilan bibliographique commenté 1974–1987, Orstom, Paris, 1989.
- [27] Paugy D., Traoré K., Diouf P.S., Faune ichtyologique des eaux douces d'Afrique de l'Ouest, in: Teugels G.G., Guégan J.-F., Albaret J.-J. (Eds.), *Biological Diversity in African Fresh- and Brackish Water Fishes, Geographical Overview*, *Ann. Mus. R. Afr. Centr., Zool., Tervuren* 275 (1994) 35–66.
- [28] Queennec G., Miles J.W., Dejoux C., Meronade B., Chemical monitoring for temephos in mud, oysters and fish from a river within the Onchocerciasis Control Programme in the Volta basin area, WHO/VBC/77-683, 1977.
- [29] Samba E.M., Le programme de lutte contre l'onchocercose en Afrique de l'Ouest : un exemple de bonne gestion de la santé publique, *Sér. Rapp. Techn. OMS*, 1995.
- [30] Welcomme R.L., *Fisheries Ecology of Floodplain Rivers*, Longman, London, 1979.