AMAZONIANA	XI	1	71 – 89	Kiel, Oktober 1989

Biomonitoring of chemicals on tropical ecosystems

by

Paul Müller

Prof. Dr. Drs. h.c. Paul Müller, Universität des Saarlandes, Institut für Biogeographie, D - 6600 Saarbrücken, F.R.G.

(accepted for publication: July 1989)

Abstract

Over the past years the environmental monitoring programmes have undergone rapid conceptual and technological advancement. Environmental monitoring (= Biomonitoring) plays an essential role in the evaluation and management of pesticides and other anthropogenic chemicals in the tropics. In the absence of effective biomonitoring, detection of serious environmental contamination and threats to human health caused by chemical pollutants may occur only after critical and irreversible damage has been done. Between 1976 and 1989 the ecosystematic effects caused by various herbicides and insecticides were analysed. The regenerative power of the tropical ecosystems, after having been treated with insecticides, does not only depend on the type of pesticide or its formulation and concentration, but also in a decisive way on the ecophysiological capacity of different organisms in the tropical food chains.

Our experience in tropical South America, Africa and Europe has proved that the application of chemicals does not represent a serious environmental problem, provided the chemical inputs on the ecosystems have already been evaluated, and the whole procedure and organization ar e carried out in a professional manner. Concerning the elimination of pests, it has been observed that various forms of land utilization in the tropics have a much more adverse effect than those effects induced by pesticide usage. The cardinal question for the time being will be: What will happen to the ecosystems when they are free of pests? This is not a scientific but a political question. There is no free lunch in the world.

Keywords: **Biomonitoring, Ecotoxicology, Residual spraying, Non-residual sequential aerosol spraying, Tropical Africa.**

Dedicated to Dr. Hans Klinge, Max-Planck-Institut, Plön, in occasion of his 60th birthday.

0065-6755 / 1989 / 071 / © MPI für Limnologie, AG Tropenökologie, Plön; INPA, Manaus

1. Introduction

The complexitys of environmental interactions in the transport, transformation and biological effects of widespread, low level chemical contaminants confound the ability of current methods to predict the possible health and environmental impacts of both new and old chemicals. We cannot transfer with certainty knowledge gained in the laboratory on the behaviour and effects of a single chemical study of an isolated living species to that gained in a natural ecosystem. However, over the past years the environmental monitoring programs have undergone rapid conceptual and technological advancement. Environmental monitoring (= Biomonitoring) plays an essential role in the evaluation and management of pesticides and other anthropogenic chemicals. In the absence of effective biomonitoring, detection of serious environmental contamination and threats to human health caused by chemical pollutants may occur only after critical and irreversible damage has been done. Between 1976 and 1989 the ecosystematic effects caused by various herbicides and insecticides were analysed. The regenerative power of the tropical ecosystems, after having been treated with insecticides, does not only depend on the type of pesticide or its formulation and concentration, but also in a decisive way on the ecophysiological capacity of different organisms in tropical food chains.

2. Chlorohydrocarbons, Carbamates, Organophosphorus compounds and Pyrethroids

Application of insecticides is currently the most common method used for controlling or eradicating pest arthropods. All the insecticides used for this purpose are non-specific, i.e. they not only kill the targets, but also affect other organisms, non-vertebrates and vertebrates. Damage to these non-target organisms may be reflected by sublethal, physiological or behavioral effects, direct mortality, long term population reduction or, in the case of persistent insecticides, be caused by bioaccumulation within the food web. The magnitude of the adverse effects depends on a range of factors, particularly the application rate and quality, the type of insecticide and formulation, the mode of application, the type of landscape covered including the vegetative cover and presence or absence of stagnant or running water, and the composition of the food web itself. The wide range of indigenous animal and plant species have all undergone the process of organic evolution and have many biochemical patterns in common. The specificity of toxic substances is thus a relative matter and it is likely that an insecticide will have some effect on various forms of life other than insects. The trend of pesticide evolution over the past 30 years, however, has been towards increased specificity. Concurrent with pesticide evolution, some arthropod species have proved to be resistant to pesticides. Development of new insecticides may be considered a practical reaction to the development of resistance (Table 1).

The pincipal insecticides utilized before World War II were inorganic compounds and/or inhibitors of the carbohydrate oxidation that produces adenosine triphosphate. The exceptions were two neurotoxic insecticides, pyrethrum and nicotine. Synthetic organochlorine insecticides were found to be remarkably residual.

Table 1: Succession of insecticides employed to control the water mosquito *Aedes nigromaculis*, the budworm *Heliothis virescens* on cotton and the two spotted spider mite *Tetranychus urticae*, 1946 - 1976 (after MÜLLER 1988a).

Aedes nigromaculis	*Heliothis virescens*	*Tetranychus urticae*
DDT	DDT	Parathion
HCH, aldrin	Toxaphene, endrin	Azinphosmethyl
Parathion, malathion	Malathion	Carbophenothion
Methyl parathion	Methyl parathion	Ovex, fenson
Fenthion	Monocrotophos	Chlorobenzilate
Chlorpyrifos	Carbaryl	Dicofol
Diflubenzuron	Chlordimeform	Tetradifon
	Synthetic pyrethroids	Propargite
	Bacillus thuringiensis	Chlordimeform
	Heliothis virus	Pentac
		Oxythioquinox
		Cyhexatin

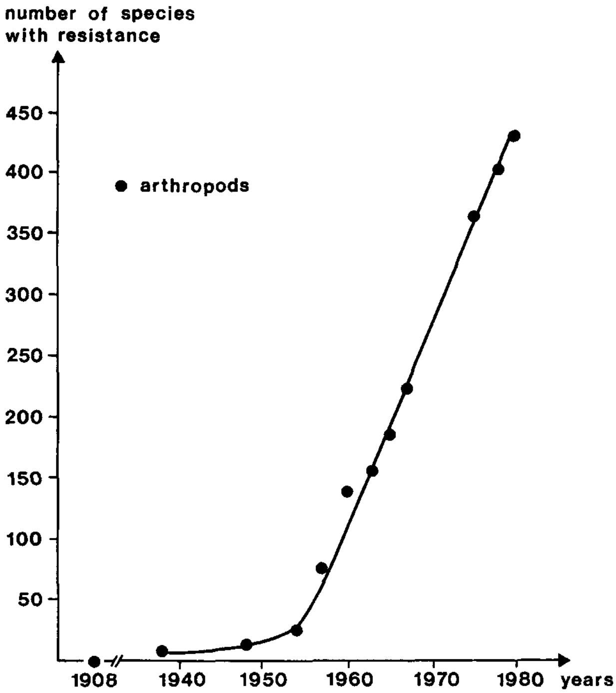

Fig. 1:
Number of species with various types of resistance (after GEORGHIOU & MELLON 1983).

Organophosphorus compounds share a common chemical structure, but they differ greatly in the details of their structure and in their physical and pharmacological properties and, consequently, in their use or in their proposed purpose. The toxic signs and symptoms that characterize poisoning by nearly all organophosphorus compounds are thought to depend on the inhibition of acetylcholinesterase. **Carbamate insecticides** inhibit cholinesterase in both insects and mammals when the substitution on nitrogen are hydrogen or methyl groups and when the substitution on ether oxygen is a relatively large moiety. The biological action of the **pyrethroids** depends on a disturbance to axonic nerve impulse conduction. In contrast to **chlorohydrocarbons** (especially DDT), organophosphates and carbamates, the precise mode of action of these pyrethroids is unknown.

3. Ecotoxicology and ecological effects

3.1 Formulation, application and ecological effects of controlled release pesticides

With the active ingredient alone we are unable to predict the reaction of natural ecosystems. Our LD_{50} values are valid only for organisms, not for biocenoses. This is why it is difficult to transfer laboratory results to natural ecosystems. The dose effect determined for many singular elements can obviously vary considerably if, for instance, there is a change in temperature (Table 2)..

Table 2: LD_{50} values (ng) for Deltamethrin and Endosulfan in *Glossina morsitans* (MARTIN & STEWART 1987)

Temperature (C°)	Deltamethrin (D)	Technical grade endosulfan (E)	Factor (E/D)
5	0.0046	7.95	1630
10	0.0082	5.98	729
12	0.0103	5.33	517
15	0.0146	4.49	308
19	0.023	3.57	155
20	0.026	3.37	130
25	0.046	2.53	55
30	0.082	1.90	23

The values given in the table clearly show that when the effects of singular elements are analysed, the dose effect, if any is present, is only valid for a specifically defined situation. Furthermore, the following points have to be taken into consideration:

(1) The relationship will depend on the chosen type of reaction.

(2) The dose effect only reflects the susceptibility of individuals and not the whole population.

(3) Because of the complexity of reactions in the biosystems, only acute mortality doses can generally be observed.

(4) For cancerogenic compounds, no effect levels can be defined.

Nowadays, we are aware that chemical mixtures will have different effects, i.e. they may show an additive effect (chlororganic solutions), a synergistic effect or an antagonistic reaction. In 1985 the United States Environmental Protection Agency proposed that the additivity should be assumed if there is insufficient data on the effects of the chemical compounds. However, the Maximum Working Place Concentration Commission of the Deutsche Forschungsgemeinschaft does not accept this proposal.

3.2 Residual spraying and non-residual sequential aerosol spraying techniques

Residual spraying with insecticides is currently the most common method used for controlling or eradicating insects, e.g. tsetse flies or locusts in Africa.

Either fixed wing aircraft or helicopters may be used for spraying insecticides with the **sequential aerosol application** techniques. First, fixed wing aircraft may be employed to apply insecticides in the form of aerosol droplets which are widely dispersed over savanna woodlands in order to make direct contact with the flies. However, only adult flies are vulnerable to this technique and repeated applications are necessary until all the pupae have emerged; each spray cycle must be completed before the female flies deposit their larvae in the soil. Although residual insecticides of the organochlorine type can be used, this technique is mainly used for non-residual chemicals. The most common insecticide in regular use today for Glossina is endosulfan. Up to six applications (low doses (14 to 20 g/ha)) may be necessary, but four are generally sufficient.

The second aerial technique involves helicopters; for example, they have been used in Cameroon (Adamaoua) to apply residual dosages of insecticides to vegetation at the edge of rivers and woodlands to control riverine and savanna flies, respectively.

3.3 Impact on targets and non-targets

3.3.1 Residual spraying in Cameroon

In Cameroon single applications of insecticides such as dieldrin or endosulfan are sprayed at dosage rates of approximately 1000 g/ha (the deltamethrin and cypermethrin doses range between 20 and 30 g/ha). In practice, a single application of dieldrin and endosulfan should secure permanent control of the flies. Tsetse flies have been eradicated from some areas of West Africa where this technique has been supplemented by ground and helicopter spraying. Most of the insecticides commonly used in tsetse control and tsetse eradication programs also cause mortality in non-targets. For this reason, the ecological effects caused by various insecticides such as DDT, dieldrin, endosulfan, deltamethrin and cypermethrin were analysed between 1976 and 1987 in Cameroon. It was found that after a dieldrin application of 900 g/ha, the effects were still detectable after 3 years, as proved by the poor population density of Gryllidae, Staphylinidae, Tenebrionidae and Diptera in particular, as well as by the residues in vertebrates. The residue values were highest 6 or 12 months after application.

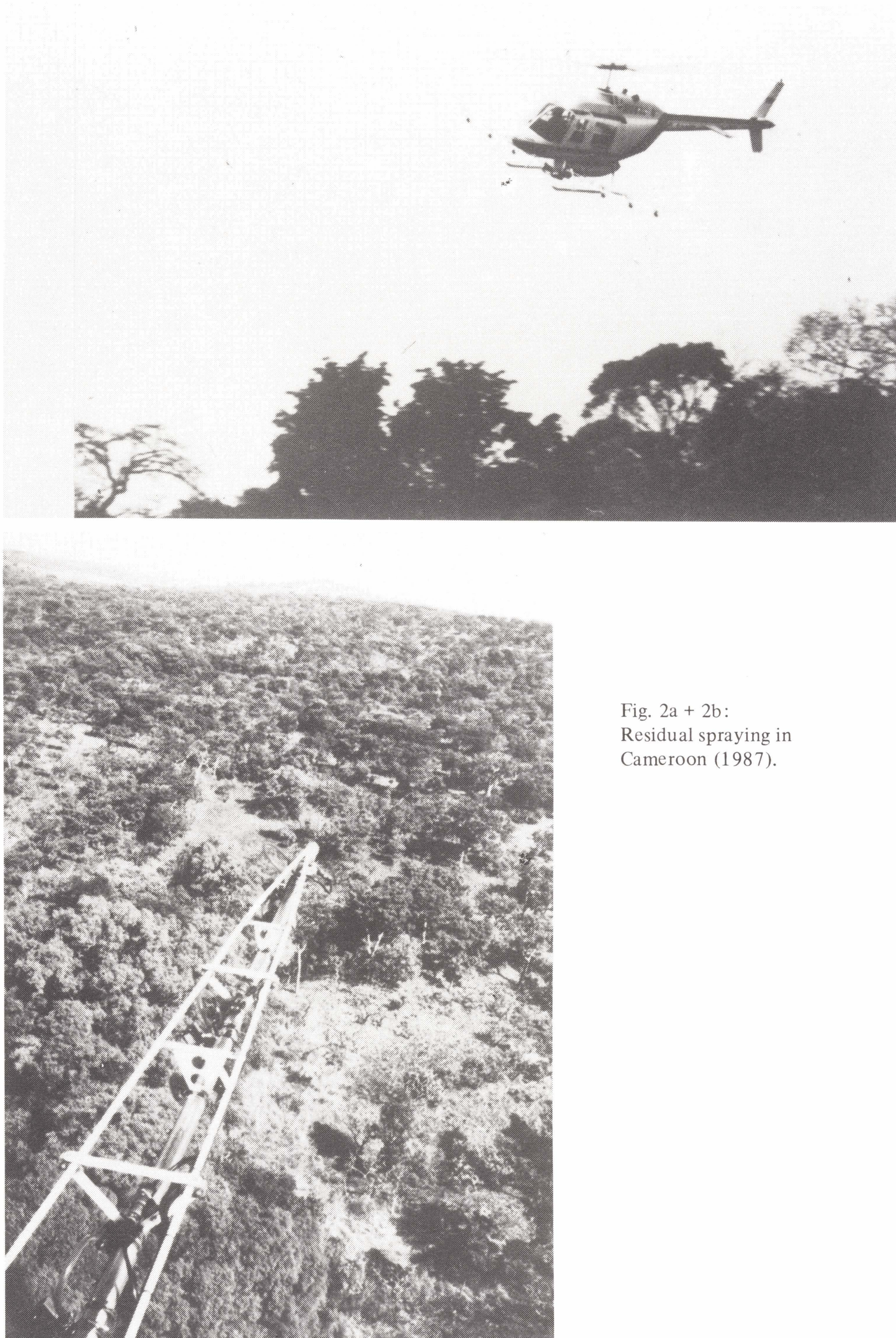

Fig. 2a + 2b:
Residual spraying in
Cameroon (1987).

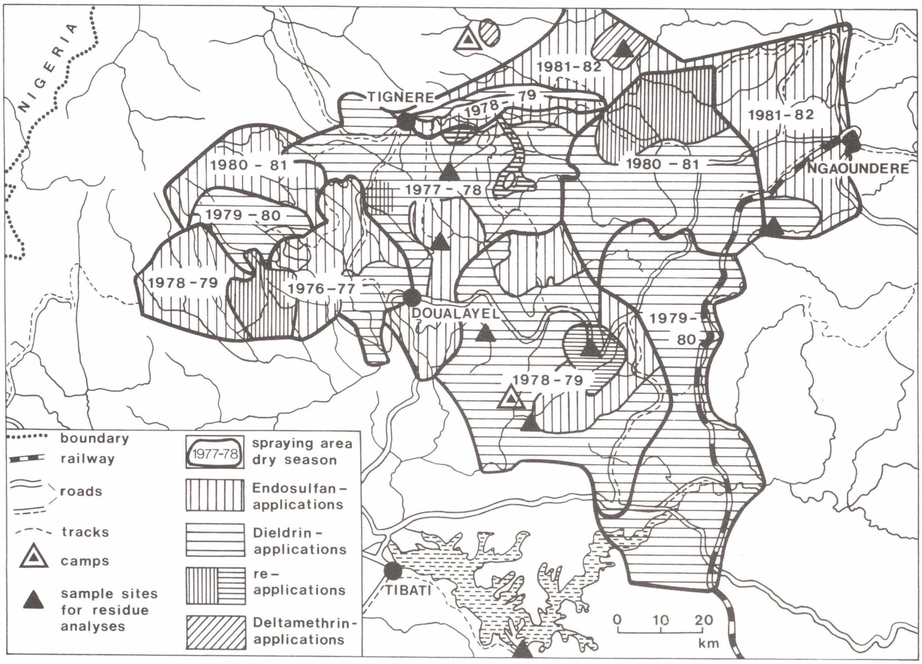

Fig. 3:
Operation area of helicopter spraying in Adamaoua (Cameroon) till the end of 1982.

Regression in and destruction of some populations were observed (Chiroptera, Soricidae). However, 5 years later vital populations of these species could be found again. The residue values detected in the non-migratory species have remained under the detection limit. After 7 years, considerable changes in land use had taken place, at least near Minim. In the area free of tsetse flies, the vegetation was not sufficiently abundant at the end of the rainy season to feed the cattle and their young. There were also clear indications of overgrazing. The gallery forest had been destroyed by man and cattle alike. Larger vertebrates (e.g. *Kobus kob, Alcelaphus buselaphus, Hippotragus equinus*) were rare or had completely disappeared from the area. It should be pointed out that it is not the application of chemicals but the uncontrolled land utilization that has destroyed the gallery forest ecosystems. The highest residue values can still be found in areas where ground spraying was carried out over the last 4 years. In general, it has been showed that deltamethrin, cypermethrin or endosulfan have little residual effect. For this reason, a guaranteed barrier effect can currently only be obtained by two insecticides, i.e. DDT and dieldrin, both of which are prohibited in the European Economic Community and the United States of America.

A number of endosulfan application areas have been analysed throughout Cameroon. Three years after spraying with endosulfan at a dosage of approximately 1000 g/ha no negative effects were observed on the gallery forest ecosystems situated in the study area north of Tignère. This can be attributed to the insecticide. However, various susceptible insectivorous species had returned. In particular, they dominated the avifauna. The residues had fallen below the detection limits. In the sprayed area west of Galim, where endosulfan was applied in 1987, adverse effects on the aquatic fauna were repeatedly observed. In smaller gallery forests, where small streams were more strongly exposed, high concentrations of the insecticide were detected on the water surface.

From the ecological point of view, multiple applications of insecticides are not acceptable for 3 years (endosulfan) and 5 years (dieldrin). The ecological damage observed in the region of Mayo Dankali (related to the high residue values for dieldrin) clearly indicates that the survival limits have been reached for savanna ecosystems. Regarding their regenerative power, the negative effects of insecticides are more serious in these regions than, for example, savanna fires or overgrazing by cattle. Deltamethrin applied at concentrations of 20 to 30 g/ha, had an acute effect on epigean arthropods. The arthropod biomass was reduced by approximately 50 % in the application areas. The total aquatic fauna was also severely affected. Eight weeks after spraying, shrimps (Natantia), Hydrometridae, Dytiscidae, Trichoptera and Culicidae were still absent.

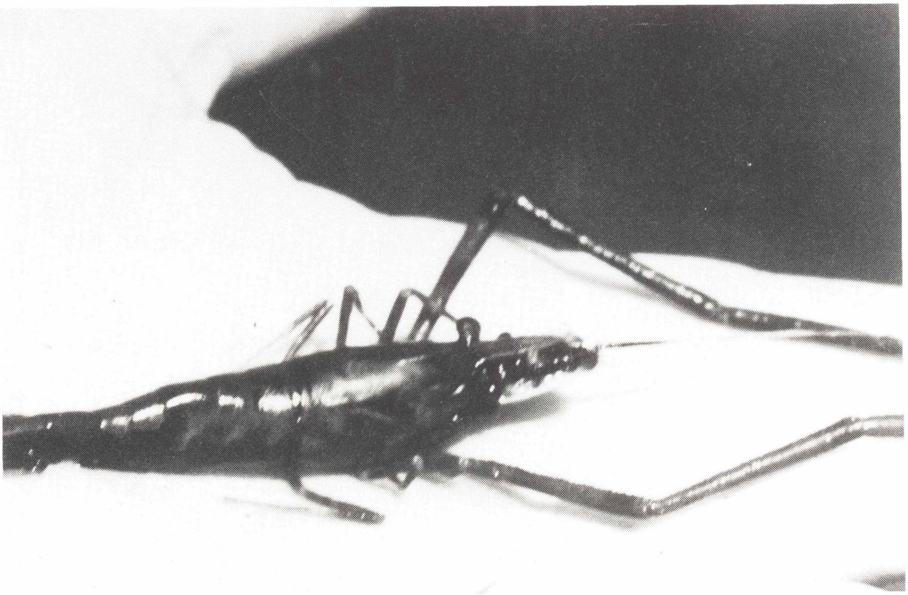

Fig. 4:
Eight weeks after Deltamethrin-spraying the shrimps *Machrobrachium niloticum* were still absent.

Five years after application, susceptible species again appeared in the sprayed areas north of Tignère. Because transhumance had obviously been better monitored, at least in 1987, no extensive savanna fires had occurred and many large animals were observed

(*Alcelaphus buselaphus, Sylvicapra grimmia, Ourebia ourebi, Cephalophus rufilatus,* etc). There was a preponderance of insectivorous species in the avifauna.

National parks pose a special problem. According to our analyses, gallery forest ecosystems need about 5 years to regenerate after a dieldrin dose of only 900 g/ha; 3 years are needed after an endosulfan dose of up to 1000 g/ha. Over this whole period, the residue values were measured, at least for the soil. The regenerative power depends on the size of the area sprayed (gallery forest, density of vegetation, unsprayed savanna). It follows from these findings, as well as from the biocenological results, that application of insecticides in national parks is unacceptable. However, large populations of *Glossina* exit in these areas. For this reason, the population density will have to be reduced along the borders of the parks. To provide additional protection, the existing protected areas, e.g. for professional hunting or game ranging, would have to be enlarged. Our experience in Africa has shown that this form of land utilization would guarantee additional protection for the national parks. In the protected areas surrounding the national parks, tsetse populations should be controlled by odor-baited targets. Residual spraying could be carried out on the border areas. In Cameroon, we have seen that every insecticide application is connected with an adverse ecological disturbance of the ecosystem and, therefore, is only acceptable if it justifies further utilization that is of advantage to the people concerned.

Unlike the apprehension sometimes raised in public discussions, we would like to point out that the insecticide doses used for tsetse control are considerably lower than other pesticides used in the tropics. However, natural ecosystems are affected more intensely by tsetse control than by agricultural utilization. Nevertheless, the most adverse effects on the gallery forests are produced by fire or extensive clearing to obtain more farmland.

3.3.2 Non-residual sequential aerosol spraying techniques in Zimbabwe and Zambia

The tsetse control operation carried out in NE Zimbabwe during the 1986 - 1988 dry seasons consisted of one main aerial control operation. Endosulfan (14 to 20 g/ha) was applied to an area of approximately 3200 km^2 in 1986. For technical reasons this area was divided into blocks: one block with odor-baited targets, partly overlapping with block 2 of the endosulfan treated area and block 3 where DDT ground spraying was carried out by the Zimbabwe Government. At the SE corner of the main control area, one separate block of approximately 500 km^2 was sprayed with deltamethrin. The timing of the aerial application of endosulfan (five spraying cycles) depended on the actual temperatures which influence the length of the pupae stage. For each cycle, fixed winged aircraft with Micron-Air equipment sprayed the insecticide from about sunset until 02:00 or 05:00 hours at about 15 m above the tree tops; the distance between each aircraft was on average 200 m.

The methods used for monitoring the effects of the endosulfan application were selected so that together they would permit evaluation of the impact of the insecticide for the ecodystematic food web as a whole. Additionally, the effects on humans were studied. Most of the investigations were conducted at the main study site and an unsprayed control area.

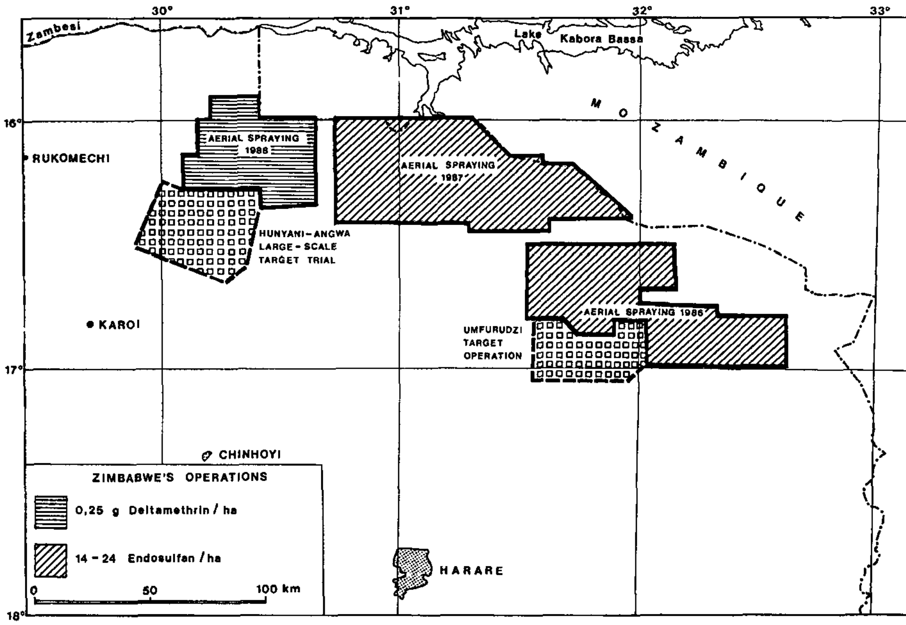

Fig. 5:
Zimbabwe's aerial spraying operation areas (1986 - 1988).

Condition indices showed that the health of birds, small mammals and cattle was unaffected throughout the whole spraying period. Gonad development in birds and small mammals underlined the good condition of these animals.

Immediate effects on terrestrial insects were clearly detectable, but no long term effects were found. There was no evidence that endosulfan killed honey bees. Immediate effects on aquatic arthropods in running water were also clearly detectable, but only predatory water beetles (Laccophilinae) were severely reduced. No effects were found on emerging insects, either in stagnant or in running water.

The fish population in rivers was clearly affected, whereas in dams only a minor number of fish died. The highest fish mortality was observed after first cycle spraying, but even at the end of operations small as well as larger fish specimens were still living in the river. Even a low dosage (14 g/ha) affects the fish population. Residues of endosulfan were detected in only 3 % of all the samples taken (except fish). The values were mostly close to the detection limit.

No endosulfan residues were found in human breast milk and urine and no serious clinical effects were detected in the local population after monitoring.

Domestic animals were also not affected by endosulfan application.

As anticipated from the results of previous studies, the Scientific Environmental Monitoring Group (SEMG) from the EEC, which carried out the spraying operations in Zimbabwe, found that there were no (or only very minor) deleterious effects on terrestrial non-target organisms, including man and domestic animals. Such effects that were recorded were of little significance in relation to the other factors causing habitat disturbance, such as subsequent land utilization, bush fires, deforestation, other pesticides and climatic variations.

The effects of stagnant water bodies such as dams and pools were very small; they usually overlapped the natural fluctuations of the fish population. As expected, fish deaths occurred in running water systems; however, at no study site was there any absence of fish. At the conclusion of spraying, different species of live fish were recovered from all the water bodies examined. However, the absence of long term effects on fish populations cannot be assumed from these observations, and further study is necessary.

Compared with the helicopter residual spraying in Cameroon, the ecological effects resulting from the non-residual sequential aerosol spraying technique were negligible.

3.3.3 Reactions of aquatic organisms to insecticide applications realized by the company 'Aer Kavango' in South-Zambia in the year 1987

Between 17th July and 2nd October 1987, 5 spraying cycles were conducted (4500 km^2) in Zambia. The time intervals were supposed to be determined by the developmental stage of the *Glossina* larvae which is temperature-dependent. The first cycle was started on 17th July and continued only until 30th July because of technical deficiencies and the breakdown of an air-craft. According to the experience made by the SEMG-ecotechnical staff at the site, it must be supposed that in most cases the application had been conducted improperly. As a result, double dosage rates, overlapping or leaving out of spraying strips have been confirmed. **This means that in the end, it was not so much a matter of analysing the environmental compatibility of the thiodan than a matter of analyzing the environmental compatibility of the application methods of the 'Aer Kavango'.**

Special attention was paid to an **insecticide accident** which happened during the spraying operations. On September 16th a pilot had to discharge 450 l of endosulfan shortly after take-off. A total surface area of 1 ha comprising three small pools in the Kalomo river had been directly affected. Two days after the accident the aquatic fauna was completely destroyed. Even after 16 days (2nd October) no aquatic organisms could be detected. The pools concerned had been pumped out in order to minimize the risk for the running waters. Lime application resulted in a pH-increase up to pH 10. With the beginning of the rainfall an adjacent pool situated at the down-stream part of the river had been analyzed on October 8th for insecticide effects. The following groups of organisms could be found: Caenidae, Notonectidae, Gerridae, Chironomidae (larvae), Brachycera (larvae), Amphibia, Pisces, Anatidae.

On October 19th further analyses had been made and fish spawn,as well as a great number of Hydrophilidae had been found. In December the Kalamo river began to flow again. The last analyses had taken place in April 1988. No stikingly negative ecological phenomena which could have been correlated with the accident have been observed.

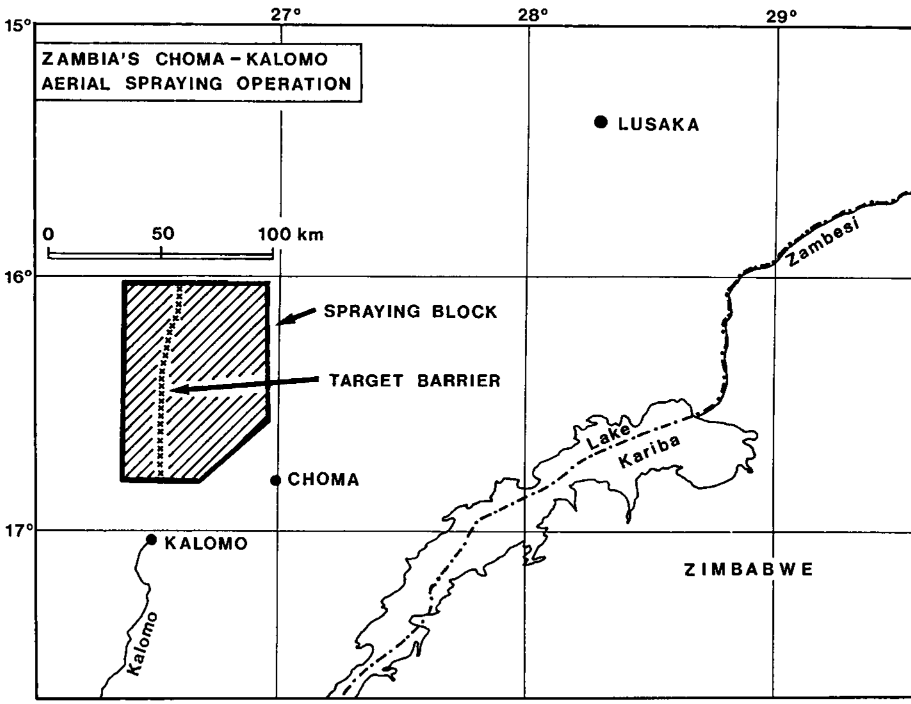

Fig. 6:
Zambias's Choma-Kalomo aerial spraying operation area in 1987.

The **invertebrate fauna** reacted directly to the quantity of the agent that was actually applied and their reactions proved to be very diverse as the data gathered from the respective evaluation methods have shown; in general, however, the reactions of the invertebrate fauna were less distinct than those of the fish species.

Abundance estimations revealed no correlation with the endosulfan applications. The fluctuations in the population from the spraying area have also been started for the control area. The question as to what extent the disappearance of the Corixidae in one dam is related to the endosulfan application must remain unanswered. The macrozoobenthos analyses also showed that the population fluctuations have not only been restricted to the spraying area.

The drift nets only supplied data during the first three or two cycles, because the Ngonga river ceased flowing on September 10th. While drift net No. 2 did not supply any data reactions, drift net No. 1 supplied a 99 % significance level during the second cycle for the groups of the Formicidae, Caenidae, Notonectidae and Gerridae. During the third cycle, only the terrestrian Apionidae (Coleoptera) showed a distinct reaction (a 95 % significance level).

The **aquatic vertebrates** reacted drastically to the application methods of the 'Aer Kavango'. The reactions of the fish species and the amphibian prove, in particular, that in comparison to the experience which the SEMG-working teams had made with endosulfan applications in Zimbabwe, the application of thiodan had not been properly executed. The concentrations on the soil in the particular case must have been in some areas much higher than 24 g/a.i./ha.

During the first, third and fourth cycles, fish and tadpole mortality could be observed (first and third cycle max. 320 dead fish/100 m; third cycle max. 800 dead tadpoles/100 m). As to Chikwangala dam, fish mortality was observed only during the first cycle (1200 dead fish/100 m on 19th July 1987, in particular *Oreochromis* and *Barbus*). The dam which had been most severely affected was the Macha dam. On August 3rd 1987, at least 47000 dead *Barbus*/100 m have been counted.

One dam which had been sprayed with 20 g/ha for trial purposes showed fish mortality only after a few days and after the application dosage had been doubled (on August 11th approx. 3600 dead *Tilapia*/100 m). At a dosage rate of 20 g/a.i./ha no considerable fish mortality was observed.

The results of the bottle traps showed a decrease in fish after each application; however, tadpoles increased. The fish species in the exposure boxes reacted considerably more sensitively than the larvae of the amphibians.

During the first cycle 10 % of *Tilapia* survived (90 % fall-out) and 40 % of *Barbus*; during the third cycle 5 % of *Tilapia* and 30 % of *Barbus* survived, and during the fifth cycle 29 % of *Tilapia* and 38 % of *Barbus* had survived.

3.3.4 Impact on and residues in ecosystems and humans (Cameroon and Zimbabwe)

Any valuable ecological monitoring will only be feasible if ecotoxicological studies are linked with the whereabouts of the noxious agents in the food web.

Apart from the size of the habitat, the migratory character of some animal and bird species will also play an essential role in interpreting the results obtained from residue analyses.

In view of the fact that large parts of **Adamaoua** had already been treated with dieldrin before spraying of the gallery forest began, it was necessary to check the dieldrin content of various species. Directly after spraying, there was a strong variation in the diverse trophic levels and individual groups investigated. This can be explained by the varying exposure of individual specimens, their different behaviour and their different habitats.

The highest contamination was detected in fructivorous bats directly after spraying, whereas the residue values for insectivorous alipeds were considerably higher only after 2 or 3 years. The residue levels of bird species, which were already low in 1981, remained constant in 1982.

The residue values in insectivorous species such as *Ispidina picta* and *Halcyon malimbica* were still high in 1981 but there was a marked drop in the level between 1981 and 1982. This can be explained by the fact that these birds feed mainly on insects and prefer savanna habitats.

The standard residue values found in four bird species, namely *Ispidina picta, Halcyon malimbica, Indicator indicator* and *Cossypha albicapilla,* were the reason why a mean for all trophically similar organisms was calculated.

Table 3 shows the characteristic residue trends for dieldrin with regard to various genera; they are valid for the period 1979 to 1983.

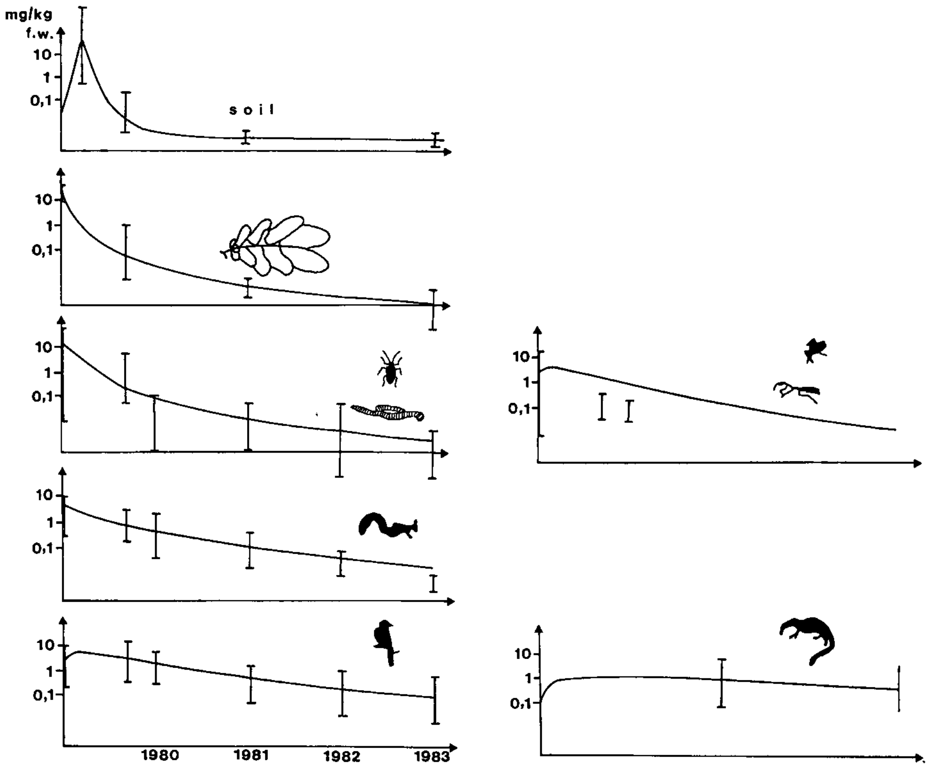

Fig. 7:
Residues of Dieldrin in different components of the food web from the treated area in Adamaoua (Cameroon) (after MÜLLER 1987, 1988b).

Table 3: Residue levels of dieldrin in animal livers in sprayed areas (mg dieldrin/kg fresh weight).

		Months after treatment					
	n	1	8	11	23	35	72
Aves (insectivorous)							
Ispidina picta	27	0.6	–	0.58	0.62	0.43	0.017
Halcyon malimbica	30	4.3	5.0	6.52	2.24	0.6	–
Aves (omnivorous)							
Turdus pelios	29	0.44	2.08	3.0	0.075	0.045	0.001
Macrochiroptera							
Micropteropus pusillus	24	136.0	–	0.14	0.075	0.065	0.0
Microchiroptera							
Hipposideros commersoni	10	3.9	–	–	0.11	0.185	–
Soricidae	6	11.3	2.3	–	–	–	0.04
Rodentia	27	0.35	0.35	0.24	0.065	0.085	0.006

In 1986 approximately 1200 wildlife samples were collected in different parts of **Zimbabwe** (the Makuti, Rukomeche, Kariba, Mt. Darwin areas). The basic data occasionally showed very high DDT residue levels but very low or no residues in other halogenated hydrocarbons. No endosulfan residues were detected in the prespray samples.

All the fish samples were collected after a single treatment in the Nyadiri River and the Kudzwe Dam. The endosulfan detection limit was 0.001 mg/kg. All the specimens analysed to date have shown insecticide residues ranging from 0.055 mg/kg in the liver of living species to 5.1 mg/kg in the liver of dead specimens, the latter obviously being the cause of death (Table 4).

Table 4: Endosulfan residue levels in different components of the food web from the treated area (1986). The DDT levels of the samples are added for comparison (mg/kg).

	Tissue	Date	Location	x days after cycle y	Endosulfan	Total DDT
Catfish (maximum level)	bo	11.8	NyR	1/II	5.10	8.05
Honey bees (n = 8)	bo	11.9	Ku	0/IV	0.100	0.013
Lycophidion capense	bo	14.9	Ku	3/IV	0.085	0.175
Anura	bo	28.8	Ku	1/III	0.045	0.024
Rodent No. 158	li	27.7	Ku	7/I	0.010	0.054
Amaurornis flavirostris	li	2.8	Ku	12/I	0.004	0.066
Lybius torquatus	br	26.8	Nya	18/II	0.004	0.006
Mabuya species	li	19.7	Ku	0/I	0.003	0.010
Hieraetus fasciatus	fe	12.9	Mu	1/IV	0.003	1.84
	li				nd	5.25
	fat				nd	723
Rodent No. 154	li	26.7	Ku	6/I	0.003	0.014
Cow milk	mi	9.8	Ku	1/II	0.003	0.009
Goat milk	mi	10.8	Ku	2/II	0.002	0.011
Elephant shrews	li	27.7	Ku	7/I	0.001	0.015
Amaurornis flavirostris	li	1.8	Ku	11/I	0.001	0.061

bo = whole body; li = liver; br = brain; fe = feather; fat = body fat; mi = milk (fresh weight);
NyR = Nyadiri River; Ku = Kudzwe Dam; Nya = Nyamatawa; Mu = Mudzi River; nd = not detectable.

The condition indices of omnivorous poultry and their gonad development did not show any significant difference between sprayed sites and the control area. Those of a small herd of cattle (muscle profile and adipose cover) did not reveal any difference between investigation periods or between sprayed and unsprayed areas.

Poultry eggs are a regular part of the food of the local population and were therefore analysed for residues of halogenated hydrocarbons (Table 5). Endosulfan has not been found in any of the egg yolks that have been analysed. It was also not present in the chicken livers. In contrast, the DDT levels were high in all samples, especially in the egg yolks.

Table 5: Residue levels of total DDT and endosulfan in the livers and eggs of chickens from the treated area (Kudzwe Dam) (mg/kg fresh weight).

	Total DDT				
	Minimum	Maximum	Mean	Median	Endosulfan
Liver (n = 24)	0.925	25.5	6.95	4.7	nd
Egg yolk (n = 12)	3.80	53.0	18.9	12.0	nd

Residues of endosulfan were found in cow milk (0.003 mg/l fresh weight, 0.160 mg/kg lipid weight) as well as in goat milk (0.002 mg/l fresh weight, 0.030 mg/kg lipid weight). These levels are above the acceptable daily intake, which is 0.008 mg/kg body weight for endosulfan.

Over the whole spraying period residue samples of breast milk and urine were taken from people living in block 1. Forty-six samples of human breast milk were analysed but no endosulfan residues were detected (detection limit: 0.02 mg/l, based on lipid weight (Table 6). Forty-four urine samples were analysed but no endosulfan residues were detected (detection limit: 0.001 mg/l). The levels of the other halogenated hydrocarbons were very low.

Table 6: Residue levels in human breast milk (mg/kg lipid weight).

	Minimum	Maximum	Mean	Median
Alpha-HCH	nd	0.90	0.11	0.02
Beta-HCH	nd	4.20	0.77	0.60
Lindane	nd	0.10	0.02	0.02
Total DDT	3.45	81.5	35.1	32.0
Endosulfan	nd	nd	nd	nd

3.3.5 Conclusions for the SEMG Bio-Monitoring 1986 to 1989

After detailed evaluation of the complete program of the field and laboratory work of the SEMG on behalf of the EEC in Zimbabwe the following conclusions can be drawn:

– The control operation in **Zimbabwe** can be regarded as successful in respect to the eradication of *Glossina morsitans* by using 14 to 24 g a.i./ha Endosulfan, 0.25 g a.i./ha Deltamethrin in odorbaited targets. There remain still problems with the eradication of *Glossina pallidipes.*

– The monitoring of endosulfan and deltamethrin indicated that the dosage used for tsetse control had little effect on the non-target fauna of the savanna biome sprayed in Zimbabwe. The adverse effects on the non-target organisms, the genetic structure and the functions of the ecosystems in the operational areas (aerial spraying and target control) can be regarded as low or negligible, in particular with regard to other impacts from different land use patterns and types, which are partially considerably more adverse.

It is clear that there are some differences in the non-target effects of deltamethrin and endosulfan as used for tsetse control, such that one compound might be chosen in preference to the other – with special reference to aquatic fauna. In areas where fisheries are important deltamethrin might be used in preference to endosulfan. In areas largely devoid of water bodies (particularly running water) endosulfan might be the insecticide of choice. Care should be taken with deltamethrin in areas where shellfisheries or other crustacea are of importance.

– Adverse direct effects on humans in the treated areas could not be detected and are absent.

– In all the various elements of the ecosystematic food web the residues of the insecticides used during the operation were either not detectable or did not indicate any risk. The residues of other chemical compounds (e.g. DDT) were generally higher or much higher than the chemicals in use during the operations.

– In Zimbabwe, the conduct of the operation as a whole, including the performance and capability of the spray-plane pilots and the organization of all different parts of the control operation including the safe handling of pesticides, was of high standard.

– The SEMG states that a comparable tsetse control operation to the EEC funded project in Zimbabwe from 1986 to 1989 can also be conducted in other areas with comparable climate, land use and vegetation patterns.

– Technical and organization related problems in **Zambia** clearly demonstrated that apart from environmental monitoring, a flexible eco-technological team must also exist, which can monitor and which can – particularly in emergency cases – not only register possible damage but can also restrict (delimit) the damage and avoid any further damage.

– Research and monitoring studies on odor-baited targets have demonstrated that with this method, too, adverse effects on certain non-target insects are likely to happen (e.g. on Stomoxyinae, Muscinae, Tabanidae). These adverse effects, however, are much less than those from large-scale aerial insecticide treatment. Yet, in future studies, these negative effects have to be investigated in more detail, particularly with regard to other bait odors, to the effects on the population of those non-target species as a whole and the relationship with the possible pollination inhibition of some plant species.

– Also as a result of the studies conducted, the SEMG underlines that for any insecticide it is necessary to know the ecosystem-specific effects in addition to the background knowledge. This means also that we cannot transfer the same application dosage, concentration or residue limits of insecticides in organisms and soil which are valid in EEC mumber states or the US to tropical or subtropical countries without evaluating those particular ecosystem-specific effects.

– There might be the need to increase the dosage of the insecticides in comparison to the environmentally monitored dosage rates during the past three years in order to cope with the *Glossina pallidipes* problem. Such a possible increase can only be implemented after close consultation with and under guidance of and monitoring by the eco-technical team.

– Pre-spray studies with regard to faunistic-floristic registration should be conducted in order to obtain the background information on possible sensitivity of the ecosystem as a whole or single elements (species).

– The SEMG recommends routine medical monitoring of pilots and ground staff associated with spraying application.

4. Criteria for acceptability of new insecticides for aerial spraying

Detailed investigations over many years have shown that endosulfan or deltamethrin can be effective against *Glossina morsitans* and is environmentally acceptable when sequentially applied as a low dosage aerosol. However, we should recognize the potential value of alternative insecticides, e.g. for aerial spraying. For new insecticides the following criteria are acceptable:

Phase I: Toxicity data for tsetse flies

Laboratory determination of toxicity should be done by precise application of the aerosol in the required droplet range to give a known dosage to adult *G. morsitans* and *G. pallidipes* within the temperature range of 4 to 35 °C. Data must be presented on insecticide toxicity to flies which cover the full range of age, nutritional and reproductive status normally encountered in a wild population.

Phase II: Small scale field trials

Aerial application by the fixed wing aerial spraying technique, or an alternative method, to an agreed block of at least 400 km^2 to test the suitability of the formulation, to assess the efficacy of the insecticide against the target insect under field conditions and to monitor the impact of insecticide application on non-target organisms should be carried out according to procedures agreed to beforehand. (To test the suitability of the formulation in collaboration with the ecotechnical staff).

5. Conclusions

Our experience in tropical South America, Africa and Europe has proved that the application of chemicals does not represent a serious environmental problem, provided the chemical inputs on the ecosystems have already been evaluated, and the whole procedure and organization are carried out in a professional manner. Concerning the elimination of pests, it has been observed that various forms of land utilization in the tropics have a much more adverse effect than those effects induced by pesticide usage. The cardinal question for the time being will be: What will happen to the ecosystems when they are free of pests? This is not a scientific but a political question. There is no free lunch in the world.

Resumo

Ao longo dos últimos anos, o monitoramento ambiental passou por rápidos progressos consepcionais e tecnológicos. Monitoramento ambiental (=biomonitoring) possui um papel essencial na avaliação e manejo de pesticidas e outros reagentes químicos antropogênicos nas regiões tropicais. Por causa da ausência de um monitoramento eficiente, a detecção de contaminações ambientais sérias e de efeitos para saúde pública, causados por puluição química, torna-se possível apenas após danos críticos e irreversíveis. Entre 1976 e 1989 foram analisados os efeitos em ecosistemas causados por diferentes herbicidas e inseticidas. O poder regenerativo de ecossistemas tropicais, muitas vezes tratados com inseticidas, não depende unicamente do tipo de pesticidas ou de sua aplicação e concentração, mas muito mais da capacidade ecofisiológica de diferentes organismos em cadeias alimentares tropicais.

Nossa experiência na América do Sul tropical, na Africa e na Europa comprovou que a aplicação de reagentes químicos não repesenta um problema ambiental sério, quando o input nos ecossistemas já foi avaliado e todo procedimento e organização foram efetuados sob forma profissional. O que se refere à eliminação de pragas, foi observado que várias formas do uso de terra nas regiões tropicais provocam mais efeitos adversos do que os introduzidos pelo uso de pesticidas. A questão crucial no futuro será: O que vai acontecer com os ecossistemas quando eles estiverem livres de pragas? Esta não é apenas uma questão crítica mas também uma questão política. Não existe almoço gratuito no mundo.

References

GEORGHIOU, G.P. & R.B. MELLON (1983): Pesticide resistance in time and space.- In: GEORGHIOU, G.P. & T. SAITO, (eds.): Pest resistance to pesticides, New York: 1 - 22.

MARTIN, R. & D.C. STEWART (1987): The efficacy of Deltamethrin for the Control of Tsetse fly by the application of Glossinex Aerial Spray.- Welcome Found., Berkhamsted.

MÜLLER, P. (1987): Ecological side effects of Dieldrin, Endosulfan, Deltamethrin and Cypermethrin application against Tsetse flies in Adamaoua, Cameroon.- GTZ, Eschborn.

MÜLLER, P. (1988a): Effects of Pesticides on Fauna and Flora.- IAEA-SM-297/40: 11 - 27, Wien.

MÜLLER, P. (1988b): Untersuchungen zur Ökotoxikologie von Cyfluthrin in Galeriewäldern von Kamerun.- BAYER AG., Monheim.

MÜLLER, P. (1988c): Untersuchungen zur Ökotoxikologie von Deltamethrin.- HOECHST AG., Frankfurt.

MÜLLER, P. (1988d): Ökotoxikologische Wirkungen von Chlorierten Kohlenwasserstoffen, Phosphorsäureestern, Carbamaten und Pyrethroiden im Nordöstlichen Sudan.- GTZ, Eschborn.