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PESTICIDES IN THE AQUATIC ENVIRONMENT

Research Memorandum

Prepared by
MONITORING AND ASSESSMENT RESEARCH CENTRE
King's College London, University of London

With the support of
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A global assessment of use and effects

By Deborah V. Chapman

A Research Memorandum (1987)

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CONTENTS

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Summary

Pesticides and their residues may enter aquatic ecosystems by way of deliberate applications in order to control pests, by unintentional run-off from agricultural areas, from industrial accidents and by inadequate disposal of wastes. This review investigates the deliberate use of pesticides in global freshwater environments and highlights those areas where pesticides are used in large quantities. The potential risk to the aquatic ecosystems is assessed in relation to the most widely used chemicals.

Data on the quantities of pesticides used are extremely difficult to obtain as not all countries require registration of quantities imported and manufactured or quantities sold and used. In addition, many of the pesticides which are most likely to affect aquatic systems are also suitable for terrestrial use and where information is made available the proportion used in each environment is usually not given. Therefore, any data relating to general use of pesticides other than in organized schemes must be assumed to be only approximately correct. Apart from information obtained from the World Health Organization's (WHO) Vector Biology and Control Division and the Food and Agriculture Organization (FAO), the data and information assessed come primarily from published literature.

There are few national or regional monitoring programmes which investigate pesticide residues in the freshwater environment apart from those intending to evaluate risk to human populations. Although agricultural run-off contributes a low level of pesticide residues to many rivers, lakes and seas, there is very little evidence of damage to aquatic ecosystems arising from presently recorded levels. In contrast, there are organized schemes using large quantities of pesticides on rivers, ponds, marshes and lakes, mostly to control the vectors of human diseases such as river blindness and malaria. For these activities there are well-documented field trials and regular monitoring is undertaken. An element of environmental damage is acceptable, particularly in some developing regions of the world in order to preserve human health. Although the principles of integrated pest management are encouraged wherever possible, there has been little development along these lines within aquatic systems, particularly in developing countries.

This review examines the major categories of aquatic pesticides, i.e. larvicides, molluscicides, herbicides and piscicides and draws together information on the principal chemicals used in world regions. A brief assessment is made of some of the observed or likely environmental effects. The use of pesticides in wet rice cultivation is discussed in a separate section, as rice paddies constitute widespread but usually temporary aquatic ecosystems. Rice is a major food crop in many developing regions of the world and the necessity for increased food production has led to a growth in pesticide use on rice.

Pesticide use and monitoring are discussed with particular relevance to developing countries as are the implications of growing pesticide use for environmental management and conservation.

1. Introduction

Pesticides have become an essential feature of agricultural practice and disease control world-wide. It was estimated by Edwards (1986) that the percentage of the world market of pesticides in 1978 was 22 per cent in developing countries and 78 per cent for the rest of the world. This was predicted to change only slightly by 1993, showing a small increase in pesticide use in the developing regions. However, for certain developing countries, such as Africa, pesticide use is expected to be three or four times greater by 1993 (Edwards 1986) and such regions may, therefore, be more at risk from possible environmental damage resulting from pesticide use.

Pesticides can enter aquatic systems by many routes which can broadly be classified as either accidental or intentional. Accidental sources of pesticides in the aquatic environment include spray drift from aerial spraying of pesticides, run-off from agricultural land, transport in airborne particles and deposition via rain, and spillages. Intentional methods include the control of aquatic pests and discharge of industrial wastes containing pesticides. A summary of pathways is presented in Figure 1.

This review highlights those pesticides which are most widely and deliberately applied to aquatic ecosystems and assesses the extent of their application. Some minor uses, such as for the control of crustaceans in fish ponds, have been omitted. The aquatic ecosystems considered are flowing waters, i.e. rivers and irrigation channels, still water bodies such as lakes and reservoirs, storage tanks and ponds, and transient water bodies such as marshes and rice paddies. It is anticipated that this review will form the basis of a

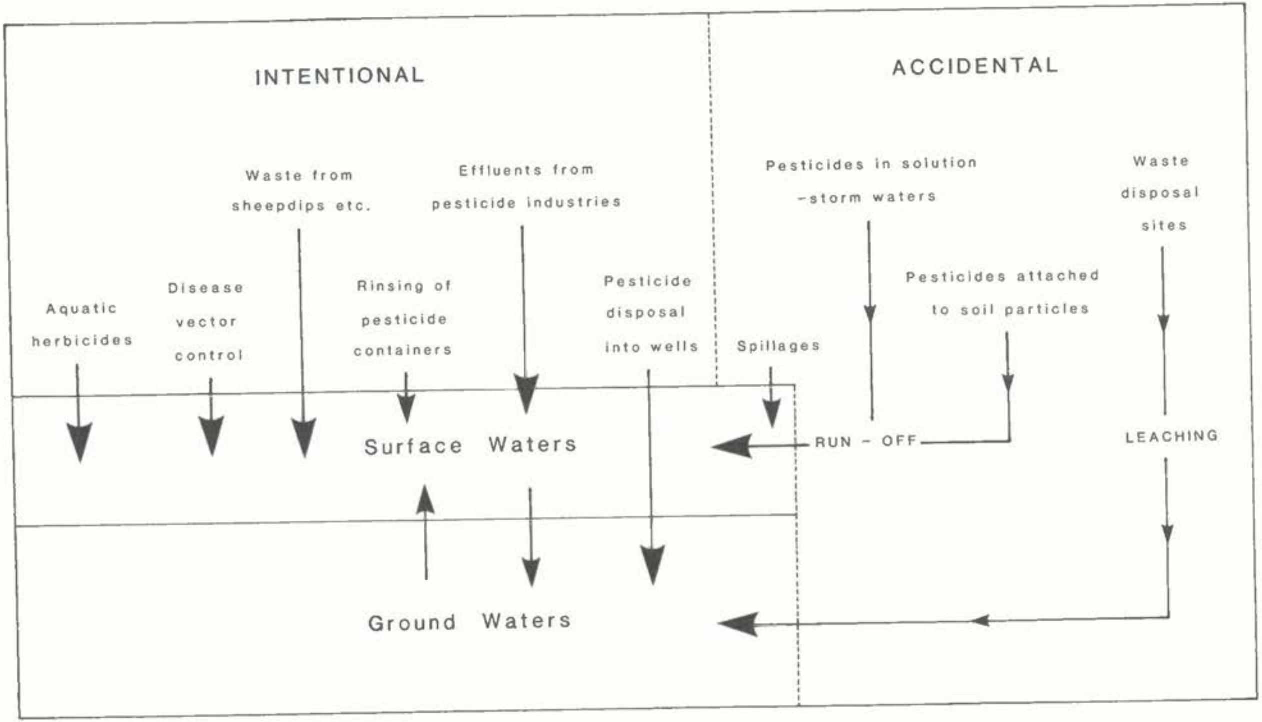

Figure 1 Sources and pathways of pesticides to fresh waters

more detailed study of the effects on aquatic ecosystems of some of the major pesticides in use. Consideration of the mode of action, behaviour, transformation and transport of specific chemicals within the environment is not, therefore, dealt with here. Information concerning specific pesticides is available from other sources besides research papers. The International Register of Potentially Toxic Chemicals (IRPTC) collects available data on chemicals including pesticides and makes the information available in the form of data profiles for each chemical; and the International Programme on Chemical Safety (IPCS) reviews many pesticides in their series of Environmental Health Criteria Documents.

1.1. Accidental inputs

Most accidental inputs of pesticides are likely to be small in quantity, except in the case of chemical spillages where the effects are usually localized (OECD 1986). However, accidental inputs could include pesticides which are not normally recommended for use in or near water due to their acute toxicity and undesirable effects in aquatic ecosystems. At present there are few monitoring programmes covering whole watersheds or investigating airborne deposition and run-off. Therefore the significance of these routes into aquatic ecosystems is difficult to assess. Agricultural run-off has led to some detectable residues of persistent organochlorine pesticides in aquatic organisms (OECD 1986).

An example of the effects of unintentional input of pesticides to an aquatic environment was an investigation of the Kinneret watershed in Israel. Although large quantities of pesticides were used in the area, the levels detected in the environment suggested no real threat to the lake itself or any of the associated water bodies (Wynne 1986). Traces of endosulfan, parathion, dorsan and trifluralin were detected in some water samples. Consistently 'high' levels were associated with the washing of aircraft spray tanks into a drainage system that connected to a canal. Nevertheless there was little evidence of accumulation of the persistent pesticides in the sediments nearby (Wynne 1986). The presence of endosulfan and lindane in fish samples was related to the illegal use of these chemicals for fishing purposes (Wynne 1986). This technique, practised previously by villagers in developing countries using natural compounds extracted from plants and now using highly toxic synthetic compounds, is an example of deliberate uncontrolled and illegal use of pesticides in aquatic ecosystems.

1.2. Intentional inputs

Apart from permitted waste discharge which should be controlled in order to produce minimal disruption, the major intentional sources of pesticides into the aquatic environment are disease vector control programmes and the use of herbicides. The major categories of pesticides used are larvicides, molluscicides and piscicides, all of which are dealt with here.

Vector control programmes can be organized on an international scale such as the Onchocerciasis Control Programme in Africa which is co-ordinated by WHO. Special units carry out the pesticide spraying programmes and liaise with the research teams appointed to investigate environmental effects of new pesticides (WHO 1985a). Reports from these schemes are available from WHO and in the published literature (e.g. Dejoux and Guillet 1980; Baker et al. 1986). On the national or regional scale local authorities may carry out control programmes on vectors such as mosquitoes or nuisance insects such as biting midges. Information from these is more difficult to obtain unless results are published in the open literature. The Vector Biology and Control Division (VBC) of WHO publishes reports on its own programmes and FAO occasionally gathers information on pesticides by means of questionnaires.

Manufacturers are reluctant to release information on the quantities of pesticides produced or sold and most published information is based on international questionnaires for which only some regulatory authorities are prepared to give answers. Although a chemical may be recommended for a certain purpose there is no certainty as to the use to which it will be put once purchased. Information on the extent of pesticide use in water bodies is often confused because many pesticides are also used on land and the statistics for use are not usually separated. Similarly the statistics on the use of chemicals against disease vectors do not always distinguish between the proportions used for each stage of the life cycle, as in Table 1.

1.3. Environmental risk

It is clear from Table 1 that the use of pesticides for such important schemes as vector control programmes in developing countries is increasing. Walsh (1985) warns that with such concentrated use of larvicides against the blackfly (the vector of river blindness or onchocerciasis) there is a danger that deleterious changes to the environment may exceed those caused by occasional accidental

Table 1 Estimates of total usage and forecast requirements of insecticides by 103 developing countries for national vector control programmes provided in response to a 1980 questionnaire (expressed in metric tonnes of active ingredient). From Smith and Lossev (1981).

Insecticide	Quantity used		Estimated quantity required				
	1978	1979	1980	1981	1982	1983	1984
Azinphos-ethyl	3.2	23.9	31.0	40.3	41.5	41.5	41.5
Bendiocarb	-	-	0.007	0.01	0.02	0.02	0.02
Bromophos	2.5	0.5	-	4.0	3.6	3.2	2.4
Bromophos-ethyl	-	0.13	0.006	0.006	0.006	0.006	0.006
Carbaryl	63.9	14.7	8.5	-	-	-	-
Chlorphoxim	7.7	13.6	72.8	-	-	-	-
Chlorpyrifos	7.8	9.2	8.4	9.9	170.1	186.2	204.0
DDT	18,669.8	25,519.7	28,819.7	28,876.7	29,078.9	36,066.0	30,215.5
Diazinon	0.3	7.0	6.0	6.0	6.0	0.2	0.2
Dichlorvos	35.0	42.7	56.0	61.3	65.0	72.5	243.4
Dieldrin	43.1	7.7	1.1	1.1	25.5	28.1	31.2
Dimethoate	9.0	9.3	2.0	17.4	17.6	18.2	18.6
Dioxacarb	0.4	0.1	-	-	-	-	-
Fenitrothion	241.6	87.43	317.8	327.8	546.5	586.1	680.8
Fenthion	45.8	81.5	72.8	89.3	130.2	116.7	119.9
HCH	9,993.7	2,320.7	3,657.7	18,332.7	18,330.6	18,432.5	18,436.8
Iodofenphos	0.4	1.2	2.4	2.4	3.0	3.0	3.0
Larvicidal oil	8,904.0	3,088.0	7,577.0	7,492.0	7,347.0	7,342.0	7,342.0
Malathion	6,629.2	6,951.6	8,134.7	8,539.9	8,472.8	8,327.6	7,896.4
Methoxychlor	-	-	0.5	0.7	1.0	1.0	1.0
Naled	3.2	41.4	5.0	2.8	4.0	4.0	4.0
Phenthoate	-	2.0	2.0	3.0	3.0	3.0	3.0
Pirimiphos-methyl	2.2	5.1	14.6	12.6	12.6	12.6	12.6
Propoxur	349.3	402.5	459.0	436.9	461.7	66.7	70.6
Pyrethroids	1.7	1.1	4.2	7.1	7.9	8.7	8.6
Pyrethrum	37.1	46.5	91.4	91.0	91.0	91.0	91.0
Temephos	181.1	223.5	247.7	273.2	298.8	601.2	306.2
Trichlorphon	2.6	8.0	15.6	10.0	11.6	14.0	15.6
Total	43,234.6	38,909.1	49,607.9	64,638.1	65,129.4	66,026.0	65,721.3

Note The figures for temephos for 1978 and 1979 include quantities used in the OCP and a projected annual use for 1980-84.

(Reproduced with permission from WHO)

pollution events. The OECD (1986) considers the major risk to water supplies in member countries to be herbicides, especially as their use is increasing. With the widespread use of some pesticides it is perhaps timely to consider the environmental effects of some of the more commonly used chemicals. Such effects can be caused by direct toxicity to target and non-target organisms and may result in indirect effects such as shortage of food species for organisms higher up the food chain. Other indirect effects may include the elimination of important predators which can upset the ecological balance or a reduction in the productivity of the ecosystem. Some effects may be chronic and less obvious, such as reduced reproductive capacity or behavioural changes.

2. Larvicides

A larvicide is a chemical used to control the aquatic larval stages of pest organisms. Larvicides probably constitute one of the largest direct intentional uses of pesticides in the aquatic environment. Consequently there are many published studies describing toxicity to target and some non-target organisms (e.g. Mulla, Majori and Arata 1979; Ware 1980). Unfortunately, however, there are relatively few adequate field studies investigating the effects on the ecosystems to which the larvicides are applied (Hurlbert 1975), except where major use is intended, such as in the organized vector control programmes (e.g. WHO 1985a). Effects on the ecosystem, therefore, have often to be deduced from laboratory studies.

The most common uses of larvicides are for the control of the blackfly, Simulium sp., and the various species of mosquito. These organisms are vectors of important human diseases and are dealt with in detail in the sections which follow. However, there are other minor uses of larvicides such as for the control of chironomid midge larvae. Numerous chemicals have been tested for this purpose, particularly in the U.S.A. (Mulla and Khasawinah 1969) and different chemicals were found to be effective against different species. Control of midge larvae is usually restricted to small water bodies of recreational importance (Mulla et al. 1971). The larvicides chosen for use were carbaryl, chlorpyrifos, fenthion, fenitrothion and temephos (Mulla et al. 1971, 1973). However, midge control probably accounts for a very small proportion of the total world use of these chemicals.

The action of larvicides may be dependent upon their being ingested and, therefore, the formulation and behaviour once in the water may be important (Ware 1983). Such stringent requirements reduce the effective choice of chemicals especially where they are to be used in running, turbid waters. Consequently on-site field trials are sometimes undertaken to choose appropriate formulations and dose rates.

2.1. Simulium control

Simulids or blackflies are vectors of human and livestock diseases in tropical areas but in the Northern Hemisphere, U.S.A., Canada, eastern Europe and Scandinavia they are also considered a nuisance because they bite both man and cattle (Jamnback 1973, 1976; Fredeen 1977a; Crosskey 1981). Consequently a great deal of effort has been directed towards control and irradication.

As Simulium lays its eggs in rivers, the larval and pupal stages are confined to the highly restricted, easily treated habitat of running water (Colbo and Wotton 1981). Control of Simulium as a vector of disease or a nuisance organism is therefore largely undertaken using larvicides.

Simulium is perhaps best known as the vector of onchocerciasis, a major endemic parasitic disease occurring in the Americas, the south-western part of the Arabian peninsula and in East, Central and West Africa. It is estimated that between 20 and 30 million people are infected by onchocerciasis throughout the world (WHO 1985a).

In the past, control of Simulium larvae was achieved using DDT (Jamnback 1973, 1981) which was found to be very effective (Garnham and McMahon 1947; Gjullin, Cope, Quisenberry and Du Chanois 1949; Gjullin, Cross and Applewhite 1950; Barnley 1958), but the possible environmental effects of using persistent pesticides for such purposes (Fredeen, Saha and Royer 1971) led to the search for alternative pesticides (Jamnback 1973). Two major chemicals emerged as suitable replacements; in North America methoxychlor was considered a suitable alternative (Fredeen 1975, 1977b) whereas Guatemala (Tabaru et al. 1982), some African countries (WHO 1985a) and other states settled for temephos (Figure 2). In the U.S.S.R., however, it appears that DDT was the last major larvicide used against Simulium attacks (Dubitskii 1981).

A detailed review of the development, testing and monitoring of the use of larvicides against Simulium sp. has been carried out by Walsh (1985).

2.2. The Onchocerciasis Control Programme

Onchocerciasis is particularly widespread in tropical Africa

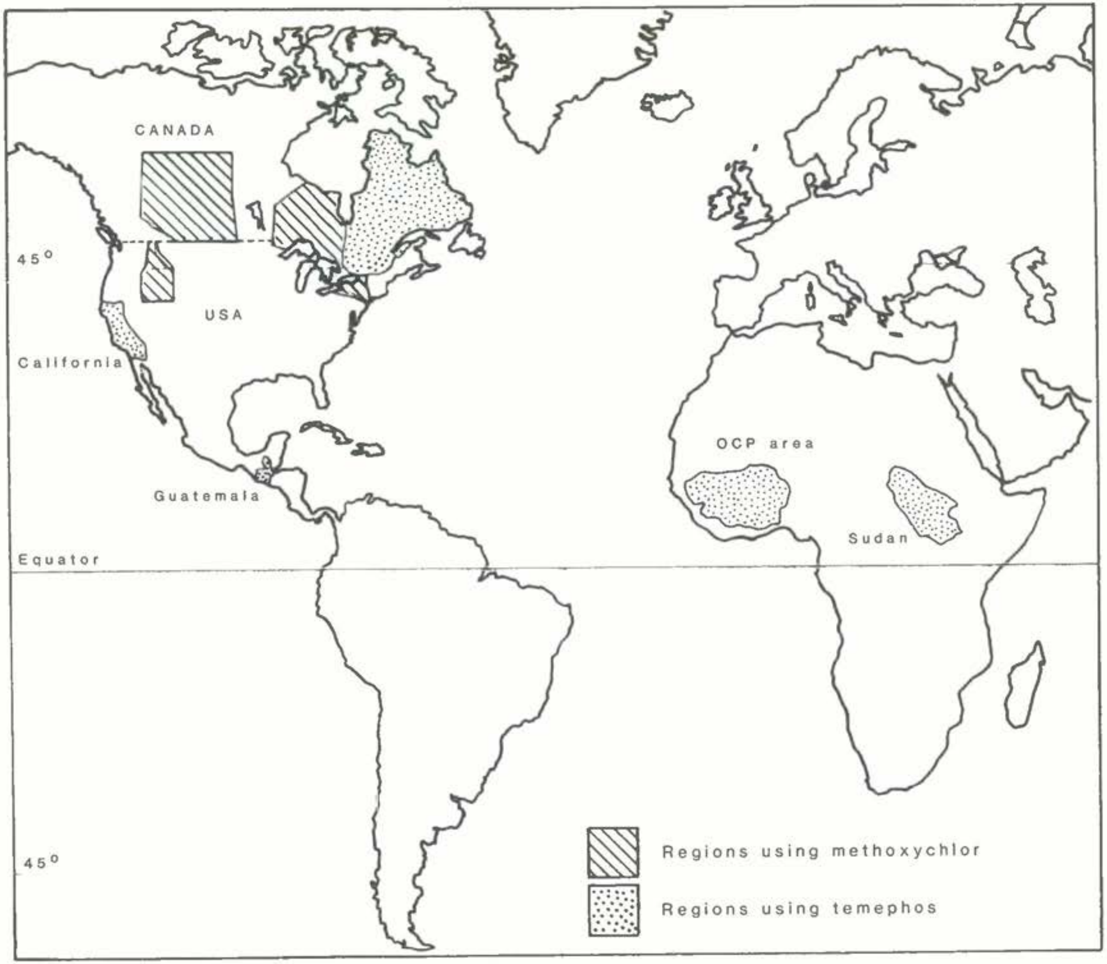

Figure 2 Regions using methoxychlor and temephos for larval blackfly control

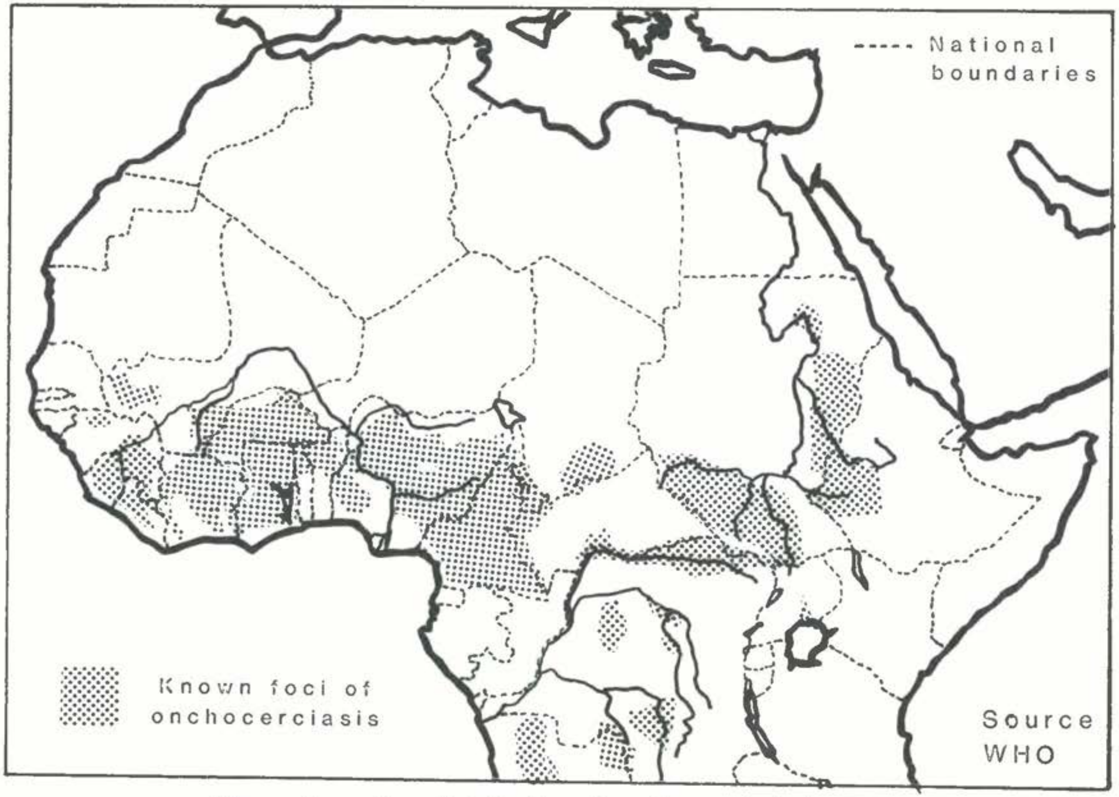

Figure 3 The distribution of onchocerciasis in Africa

(Figure 3) and attempts to contain the disease have been made since about 1950 (e.g. Garnham and McMahon 1947; Barnley 1958). As a result of some success in controlling onchocerciasis, WHO launched the Onchocerciasis Control Programme (OCP) in the Volta River Basin area in 1974 (Walsh, Davies and Cliff 1981; Pugh Thomas 1982; WHO 1985a). This area covering 654,000 km^2 over seven countries (Benin, Burkina Faso, Côte d'Ivoire, Ghana, Mali, Niger and Togo) was to be treated with larvicides for a period of 20 years. A further 110,000 km^2 in Côte d'Ivoire were included in the programme in 1978/1979 and a possible 111,000 km^2 south of the area in 1984 (Figure 4). A western extension of the programme was also proposed to begin in 1986 to cover areas responsible for reinvasion (Kelly et al. 1986). Some areas responsible for reinvasion were identified in eastern Guinea and some prevention of reinvasion of Mali was successfully achieved in some trials during 1984 and 1985 (Baker et al. 1986). The strategy adopted was to treat all riverine breeding sites weekly with 0.15 litres (wet season May-October) or 0.3 litres (dry season November-April) of Abate(R) (temephos) per cubic metre of river per second. This is equivalent to concentrations of 0.05 and 0.1 mg ℓ^{-1} of temephos per ten minutes respectively.

The areas introduced for larvicide treatment and the lengths of rivers regularly receiving pesticides as part of the OCP are given in Table 2. As of 1984 a maximum of 24,505 km of rivers in the high-water rainy season were being sprayed weekly with larvicides and when the programme is fully implemented 50,000 km of river will be brought under control. This, therefore, probably constitutes the largest single scheme responsible for using pesticides in the aquatic environment.

By 1979 a total of 840,449 litres of temephos had already been applied, when in 1980 resistance was detected in some species of Simulium in Côte d'Ivoire. The only replacement larvicide available was chlorphoxim. This was applied initially at 0.025 mg ℓ^{-1} per ten minutes and later at the same dose rate as temephos, as and where resistance was found (WHO 1985a). Unfortunately dual resistance to chlorphoxim and temephos then occurred. This led to the use of Tecknar(R) a formulation of Bacillus thuringiensis var. israelensis serotype H-14, commonly called Bti H-14. This is an insecticide of biological origin where the effective agent is an endotoxin present in the form of protein crystals produced by the bacterium and found to be highly effective against Simulium (WHO 1985a). It has been used mostly in rivers with discharge rates below 50 m^3 s^{-1} but was introduced into most areas with resistant blackfly as they occurred.

As resistance to chlorphoxim was only temporary in some areas,

Table 2 The extent of the use of larvicides by the Onchocerciasis Control Programme.

Phase of Programme	I	II	III West	III East	IV	Southern extension	Total
Date larviciding started	Feb. 1975	Mar. 1976	Mar. 1977	Jul. 1977	Apr. 1978	1984	at 1984
Area treated 1,000 km ^{2}	247	134	77	196	110	111	875
Length of watercourses treated-max (km)	4,800	2,575	3,150	4,650	3,500	5,830	24,505

Source WHO 1985a

Table 3 Quantities of insecticides used in the OCP expressed as litres of marketed preparation.

	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986*
Temephos	75,631	129,947	155,615	215,879	263,377	184,517	130,000	162,750	74,807	77,849	130,118	60,508
Chlorphoxim	-	-	-	-	-	5,713	70,000	6,699	35,796	56,685	9,856	18,377
Tecknar(R)	-	-	-	-	-	416	1,500	232,986	310,000	256,853$^+$	217,169	265,653
Permethrin	-	-	-	-	-	-	-	-	-	5,204	2,968	82,322
Carbosulfan	-	-	-	-	-	-	-	-	-	-	5,286	7,013

Source WHO 1985a and personal communication

Notes
* Data available for January - September only
\+ Bti H-14 and HPD

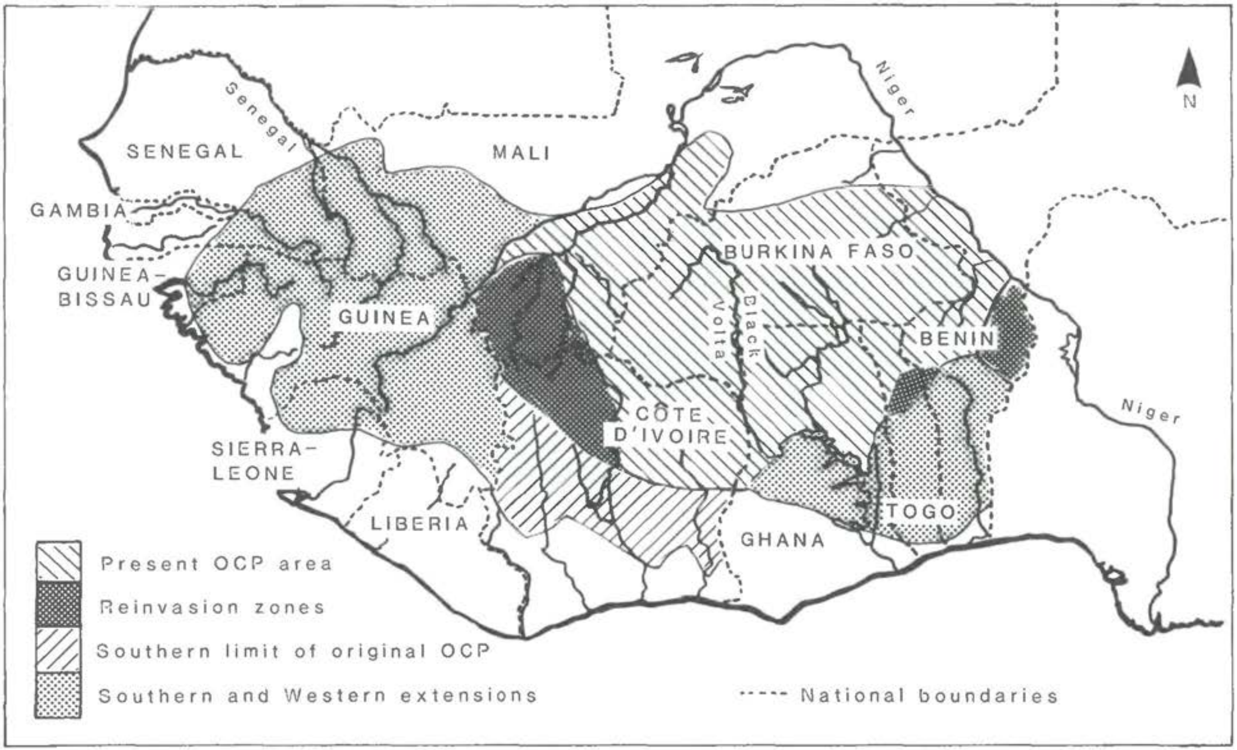

Figure 4 The Onchocerciasis Control Programme areas of West Africa

rivers were treated with Bti H-14 and chlorphoxim in turn. The increased use of Tecknar(R) since 1980 can be seen in Table 3, although new improved formulations have now reduced the quantities required. The large quantities used result from the fact that it takes 15 to 20 times as much Tecknar(R) to treat the same stretch of watercourse as it would using temephos (WHO 1985a). The use of Tecknar(R) is, therefore, expensive and alternative larvicides are being sought. Permethrin, a pyrethroid insecticide, has been found to be very effective as a blackfly larvicide (WHO 1985a) but has more serious effects on non-target fauna. It is now being used occasionally by the OCP in the rainy season as is carbosulfan, a carbamate insecticide (WHO personal communication) (Table 3).

The effects on the aquatic environment and the fauna of the OCP area of such extensive use of larvicides have been reviewed by Walsh (1985), WHO (1985a) and Shiff (1986). In the short term, downstream drift of the invertebrate populations increased for up to 24 hours after treatment and 20 to 25 per cent of the organisms were lost (WHO 1985a). It was noted that only macrocrustaceans (e.g. prawns) and fish were not affected. Those organisms susceptible to drifting downstream were eliminated from the rivers after several weeks of repeated applications of larvicides (Walsh 1985; WHO 1985a). However, untreated sections of the river provided refuge for the organisms which began to repopulate treated sites after a year or so. Although species composition and abundance changed, the diversity of the communities suggested a new ecological balance had been achieved (WHO 1985a). Some of the organisms which became more abundant, such as the Chironomidae, may have done so as a result of reduction in predators (WHO 1985a) although they are also regarded as pollution indicator species (Walsh 1985).

The overall conclusion of the ecology group responsible for monitoring the environmental impact of blackfly control is that no major imbalance has been noted and that the invertebrate and fish fauna appear relatively unaffected (Shiff 1986). However, changes in fish populations occur more slowly and may be affected by other environmental factors, and it may take some time for the changes due to larvicides to manifest themselves. Declines in fish catches in treated rivers are apparently similar to those in untreated rivers (Walsh 1985; WHO 1985a). In reviewing the effect of the use of temephos, Opong-Mensah (1984) has noted irreversible inhibition of acetylcholinesterase activity and some bioaccumulation of temephos and residues in fish. He claims that the residual toxicity and low levels of exposure may cause some long-term effects in fish populations.

With the increasing use of alternative larvicides in some areas (Table 2) affecting different non-target organisms, the stability of the aquatic ecosystems may be affected especially where several alternative chemicals are tried at one site or where one or two larvicides are regularly alternated to prevent resistance. The use of Bti H-14 has produced no noticeable environmental effects (WHO 1985a) but chlorphoxim has been shown to produce more severe effects on invertebrate fauna than temephos (Walsh 1985). Although fish may not be directly affected there may be a reduction in available fish food species.

Permethrin, which has been used since 1984 (Table 3), is a synthetic pyrethroid. From the limited information available from field trials, Walsh (1985) concluded that pyrethroids were too toxic for use as larvicides in the field although permethrin was the least toxic. A detailed review of the effects of pyrethroids on aquatic ecosystems has been carried out by NRCC (1986). At normal application rates pyrethroids are not toxic to fish although juveniles may be sensitive. Many invertebrates, however, including shellfish which are important for food, are very susceptible to these chemicals. Population growth and the reproductive rate of fish can therefore be affected by the decline and change in their food supply (NRCC 1986). The high toxicity of pyrethroid insecticides within the aquatic ecosystem needs careful consideration when extensive use is planned (NRCC 1986).

2.3 Other Simulium control programmes

In view of the success of the OCP a similar approach was taken on a local scale to control onchocerciasis in south-western Sudan (Baker and Abdelnur 1986a,b). Temephos was applied to a 41.3 km stretch of the Bussere River at 0.05 or 1.0 mg ℓ^{-1} (depending on river flow rate) between the months of May and January. This scheme proved successful for localized control of the disease.

Unlike in the large rivers of Africa, the Simulium species which is the vector for onchocerciasis in Guatemala breeds in numerous small tributaries flowing at about 0.1-1.0 $\ell\ s^{-1}$ and surrounded by forests. After testing both temephos and fenitrothion (Tabaru et al. 1982) a suitable programme was devised using slow release briquettes of 10 per cent temephos to give a dosage of 1 mg ℓ^{-1} per ten minutes at intervals of two weeks or less.

The Guatemalian vector control operation commenced in March 1979 in the Lavaderos River with 47 sites in 24 tributaries. By September 1979 a total of 88 sites were being treated every two weeks. In June 1979 larviciding commenced in the Barretal and Zapote River basin at 83 sites on 44 tributaries and in March 1980 the Guachipilin River basin with a further 140 tributaries joined the scheme (Ogata 1981). At present there is no information on the total quantity of pesticides used although this scheme clearly represents another major source of temephos in the aquatic environment.

Other states and countries reported to use temephos to control blackflies include Quebec and Labrador in Canada (Wallace, West, Downe and Hynes 1973), California in the U.S.A. (Pelsue, McFarland and Magy 1970) and southern Sudan (Jamnback 1976).

Owing to its effectiveness as a replacement for DDT, methoxychlor has been adopted for Simulium control by some states in temperate zones. The effects of both chemicals were studied in the Adirondack region of New York State by Burdick, Dean, Skea and Frisa (1974). Methoxychlor concentrations of 0.008 mg ℓ^{-1} per five minutes were found to be effective in New York State, U.S.A. and Ontario, Canada where the larvicide was applied by aircraft at a rate of 4.5 litres of 15 per cent methoxychlor per flight mile, i.e. approximately 2.8 ℓ per kilometre (Jamnback 1976).

A major control programme was initiated in Alberta, Canada in 1974 to control blackfly in the Athabasca River (Haufe and Croome 1980). Methoxychlor, at a concentration of 0.3 mg ℓ^{-1} was found to be effective and between June 1974 and May 1976 a total of 1,527 litres of methoxychlor (21-25 per cent concentration) was used in four separate applications (Depner, Charnetski and Haufe 1980). Most of the control of Simulium achieved was as a result of direct mortality whereas at lower concentrations it caused detachment of the larvae and drift downstream (Charnetski, Depner and Beltaos 1980). Two annual applications of methoxychlor have remained the major method of control up until 1986 when this programme was scheduled to cease.

On the basis of extensive tests using methoxychlor in the Saskatchewan River in western Canada between 1968 and 1973 (Fredeen 1974, 1975) it was considered an effective replacement for DDT (Fredeen 1975, 1977b). It is applied at a single point to large rivers at between 0.18 and 0.31 mg ℓ^{-1}. In Idaho, western U.S.A., applications of 0.3 mg ℓ^{-1} per 15 minutes of methoxychlor emulsion are used to control Simulium in irrigation canals (Jamnback 1976).

The use of methoxychlor in the Saskatchewan and Athabasca rivers prompted an assessment by NRCC (1983) of its impact on rivers and streams. The report concluded that there was insufficient information concerning the effects of methoxychlor on the aquatic environment and organisms in the field, especially fish. Although invertebrate numbers declined after treatment of the rivers and their detachment and downstream drift increased, there was little information on the rate of recovery and recolonization. There are some suggestions of chronic toxicity to fish, and effects on fish populations due to a decline in food species. Nevertheless, information is inadequate and carefully planned monitoring programmes are recommended where methoxychlor is intended to be used (NRCC 1983). However, as foreseen by NRCC (1982) the use of methoxychlor is currently being replaced by Bti H-14 in Saskatchewan (Taylor, personal communication).

2.4. Mosquito control

Mosquitoes are found throughout the world, with the exception of Antarctica (Service 1986), and are considered a pest in many areas. The adults of some species are important vectors of some major human diseases such as malaria (Figure 5), filariasis and yellow fever (WHO 1984; Service 1986), and the bulk of pesticides used in most nationwide vector control programmes are for antimalaria operations (Smith and Lossev 1981). Mosquitoes lay their eggs in or near almost any water body so long as it is not fast flowing. Larvae are commonly found in swamps and marshes, ponds, pools, rainwater puddles, rock pools, ricefields, ditches, drains and water tanks.

Control of mosquitoes, which may be practised in virtually all countries at some time or other, can be directed at the terrestrial adult or aquatic larval stage. As both methods of control may be used together in some countries, statistics on the quantities of pesticides applied to terrestrial and aquatic habitats are not usually separated as in Table 1. A review of mosquito control in aquatic systems and the associated environmental effects has been carried out by Mulla et al. (1979). According to a more recent article by Service (1986) the most favoured chemicals for use as mosquito larvicides are organophosphates (e.g. malathion, chlorpyrifos, temephos and pirimiphos-methyl) and carbamate insecticides, such as carbaryl. A list of the pesticides registered for use in the U.S.A. has been compiled by Rathburn (1979) and a summary of the larvicides is given in Table 4. Several other chemicals are also approved by WHO (1984) as indicated in Table 5.

Data on the pesticides used for mosquito and other vector control programmes have been collected and collated by Smith and Lossev (1981) (Table 1). Although it can be assumed from their data that some chemicals were used for direct aquatic application, e.g. temephos, no distinction in the use for terrestrial and aquatic

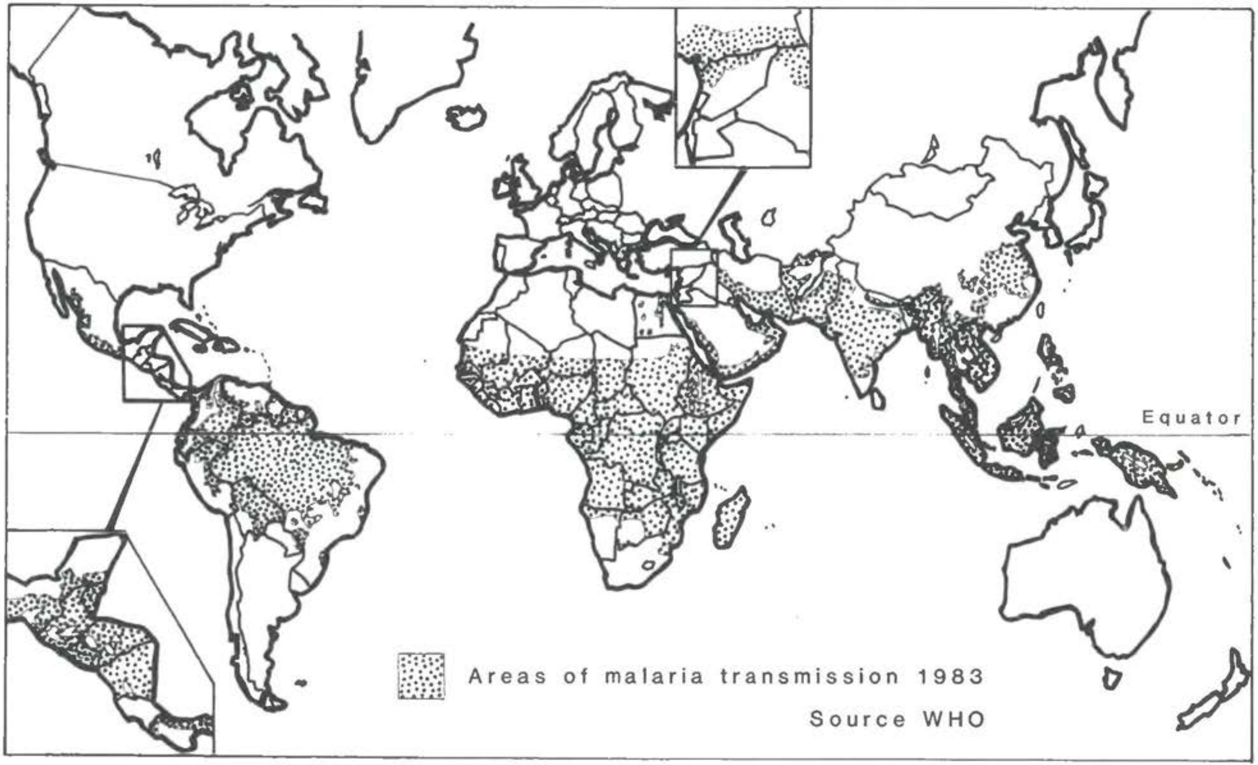

Figure 5 Regions where malaria transmission occurs

Table 4 Pesticides registered for use for larval mosquito control in the U.S.A. together with some recommendations for application rates.

Insecticide	Trade Name	% Concentration	Application Rate
Methoprene	Altosid SR-10	10.0	3.7-5.0 g ha^{-1} a.i.
	SR-10 sand granular	0.2	3.7 g ha^{-1} a.i.
	Altosid briquettes	4.0	1 per 9.3 m^2
Oils	Flit MLO	98.8	1.5-7.7 ℓ ha^{-1}
	Fla mosquito larvicide	99.56	4.6-9.2 ℓ ha^{-1}
Chlorpyrifos	Dursban M	41.2	2.3-9.2 g ha^{-1} a.i.
	Dursban 2E	22.4	2.3-9.2 g ha^{-1} a.i.
	Dursban 10CR	10.6	1.5 mg $ℓ^{-1}$
	Dursban 1G	1.0	4.6-91.9 g ha^{-1} a.i.
Fenthion	Baytex LC	93.0	9.0-18.4 g ha^{-1} a.i.
	Baytex 4	45.0	9.2-18.4 g ha^{-1} a.i.
Malathion	Cythion	91.0	91.9 g ha^{-1} a.i.
	Cythion EL	57.0	91.9 g ha^{-1} a.i.
Temephos	Abate 4E	43.0	2.9-86.4 g ha^{-1} a.i.
	Abate 1G	1.0	9.2-36.8 g ha^{-1} a.i.
	Abate 2G	2.0	9.2-91.9 g ha^{-1} a.i.
	Abate 5G	5.0	18.4-91.9 g ha^{-1} a.i.

Note a.i. - active ingredient

Source Rathburn (1979)

application was made. According to the data supplied by 103 developing countries (used for the preparation of Table 1) the use of temephos represented only 0.4-1 per cent of total pesticide use from 1978 to 1984 whereas larvicidal oil (petroleum hydrocarbon mixtures) represented 7.9-19.7 per cent (Smith and Lossev 1981). Larvicidal oil was only reported to be used in South-East Asia and the eastern Mediterranean region. In a review of the development and use of numerous larvicides against mosquitoes in California, U.S.A., Mulla (1977) highlighted a trend towards increased use of larvicidal oil. This was largely due to the increased resistance or tolerance of several mosquito species to the most commonly used and effective compounds, e.g. DDT, malathion and parathion. The approximate application rate for larvicidal oil is given at 10-25 ℓ ha^{-1} (Mulla et al. 1979).

Table 5 Insecticides suitable as larvicides in mosquito control

Insecticide	Chemical type[a]	Dosage (a.i.)[b] g ha^{-1}
Chlorphoxim	OP	100
Chlorpyrifos	OP	11-25
Deltamethrin	PY	2.5-10[c]
Diflubenzuron	IGR	25-100
Fenitrothion	OP	100-1000
Fenthion	OP	22-112
Fuel (larvicidal) oil	-	d
Iodofenphos	OP	50-100
Malathion	OP	224-1000
Methoprene	IGR	100-1000
Paris green	CA	840-1000
Permethrin	PY	5-10[c]
Phoxim	OP	100
Pirimiphos-methyl	OP	50-500
Temephos	OP	56-112

a OP = organophosphorus compound; PY = synthetic pyrethroid; IGR = insect growth regulator; CA = copper-arsenic complex
b a.i. = active ingredient
c The lowest levels are recommended for fish-bearing waters
d Apply at 142-190 ℓ ha^{-1} or 19-47 ℓ ha^{-1} if a spreading agent is added.

Source WHO (1984)

Statistics supplied for the African region, which concentrated only on malaria and mosquito control, suggested between 73 and 93 per cent of all mosquito control between 1978 and 1984 would be achieved using DDT (Smith and Lossev 1981). Although DDT has been used as a larvicide (Fredeen et al. 1971) the risks of biomagnification of organochlorines and the development of resistance has led to the more restricted use for indoor spraying (Mulla et al. 1979; Morrallo-Rejesus 1983; Edwards 1986).

In common with blackfly control, organophosphate pesticides have proved most effective as larvicides for mosquito control (Mulla et al. 1979). Of those chemicals mentioned as still in use (fenthion, temephos, chlorpyrifos, methyl parathion and malathion), data are available in Smith and Lossev (1981) for all but methyl parathion. Applied at the rate of 50-110 g ha^{-1}, fenthion, temephos and chlorpyrifos are all effective although chlorpyrifos is the most effective at those concentrations (Mulla et al. 1979). Temephos, at the low dosage required (0.1 kg ha^{-1}) is safe to humans and costs about one-tenth as much as larvicidal oil (WHO 1984). Malathion requires application at higher rates (0.5 kg ha^{-1}) and may, therefore, have greater adverse effects on non-target organisms. Together with the added cost, this probably restricts its use as a larvicide although it is reported to be used on some mosquito breeding grounds such as marshes (McEwan and Stephenson 1979). In all areas surveyed, the quantities of malathion used were greater than the other chemicals (Smith and Lossev 1981) but this may be due to significant terrestrial uses as a substitute for DDT. WHO (1984) does not recommend the use of parathion and methyl parathion because of their high mammalian toxicity and associated risk to human populations.

Recent use of fenthion in the U.S.A. as a mosquito larvicide has been indicated by Powell (1984) who studied the effect on birds nesting in flood-irrigated hay meadows treated with fenthion at 52 g active ingredient (a.i.) per hectare and Smith, Spann and Hill (1986) who studied the effects on wading birds in a simulated shallow wetland treated with 112-1120 g ha^{-1} (a.i.). Both fenthion and chlorpyrifos are reported to be particularly suitable for use in polluted waters at 0.5-10 mg ℓ^{-1} (WHO 1984).

Temephos was the most favoured mosquito larvicide in southern Ontario, Canada (Helson, Surgeoner and Ralley 1979) but recent use on salt marshes on the Atlantic coast of the U.S.A. has led to concern over the health of mallard ducklings (Fleming, Heinz, Franson and Rattner 1985). The low toxicity of temephos has permitted its recommendation and use to control mosquitoes in potable water tanks at a maximum dose of 1 mg ℓ^{-1} (Laws et al. 1968; WHO 1984). Methoprene is also considered safe for this purpose (WHO 1984). The practice of collecting rainwater for household use in tropical areas provides additional breeding sites for mosquitoes and various insecticides have in the past been tested in such tanks, including DDT (Brooks, Schoof and Smith 1965).

In the African region an increase was predicted in the use of chlorpyrifos for mosquito control from 3.6 tonnes (a.i.) in 1978 to 199 tonnes (a.i.) in 1984 (Smith and Lossev 1981). A more dramatic increase was reported for temephos, 0.3 tonnes (a.i.) in 1978 to 29 tonnes (a.i.) in 1984. Small estimated increases in the use of temephos for all vector control programmes were also predicted by the eastern Mediterranean, South-East Asian and European regions, although the quantities used were small, between 10 and 62 tonnes (a.i.) per year for the whole region (Smith and Lossev 1981). In reports on mosquito control in Ontario, Canada (Surgeoner and Helson 1982; Mackenzie, Braun and Frank 1983), that state alone used approximately 7 tonnes of temephos from 1974-1980 on nearly 8,000 ha of permanent and temporary pools and ditches.

Apart from 40-50 tonnes (a.i.) per year of fenthion used by the eastern Mediterranean and South-East Asian regions and a predicted use of 23-28 tonnes (a.i.) in the African region, all other larvicide use was minor (Smith and Lossev 1981).

According to Mulla et al. (1979) organocarbamates have been tested for use as mosquito larvicides but none have been widely adopted for control operations. Instead, however, some insect growth regulators and insect developmental inhibitors have been found useful. The two most effective compounds are methoprene and diflubenzuron. Methoprene has been successfully used with no adverse effects in ponds and irrigated pastures (Miura and Takahashi 1973; Schaefer and Wilder 1973). Diflubenzuron has been successfully used in ponds and lakes in the U.S.A. (Ali and Mulla 1978; Apperson et al. 1978). However, in the U.S.S.R. Kerbabayev, Strel'nikova and Stetsurenko (1985) report some mortality in non-target fauna, especially crustaceans, in field trials at concentrations of diflubenzuron ranging from 10 to 30 g ha^{-1} (a.i.) (0.0015-0.012 mg ℓ^{-1}). A more detailed review of the effects of both chemicals is given by Mulla et al. (1979) and of diflubenzuron by Cunningham (1986). However, little indication is given as to the extent of their general use. Methods of encapsulating diflubenzuron to increase its residual activity as a low-dose, slow-release larvicide are being investigated (Knapp and Nontapan 1980). However, there are already reports of cross resistance to methoprene and diflubenzuron with DDT resistance in mosquitoes (Sparks and Hammock 1983).

Despite recent interest in the use of synthetic pyrethroids to control mosquito larvae there is little information available at present and compared with other chemicals the quantities used (which include terrestrial use) would appear to be minor (Smith and Lossev 1981). Other chemicals such as organotins, normally used as molluscicides, have also been tested against mosquito larvae (Cardarelli 1978) and found to be effective. However, there is little evidence that they are being widely used in this context. Bti H-14, the insecticide of bacterial origin used against <u>Simulium</u>, is also effective against mosquitoes. Its use in certain urban situations, e.g. in New Orleans, U.S.A., has been reported by Smith and Gratz (1984). Florida, which is reputed to spend more than other states in

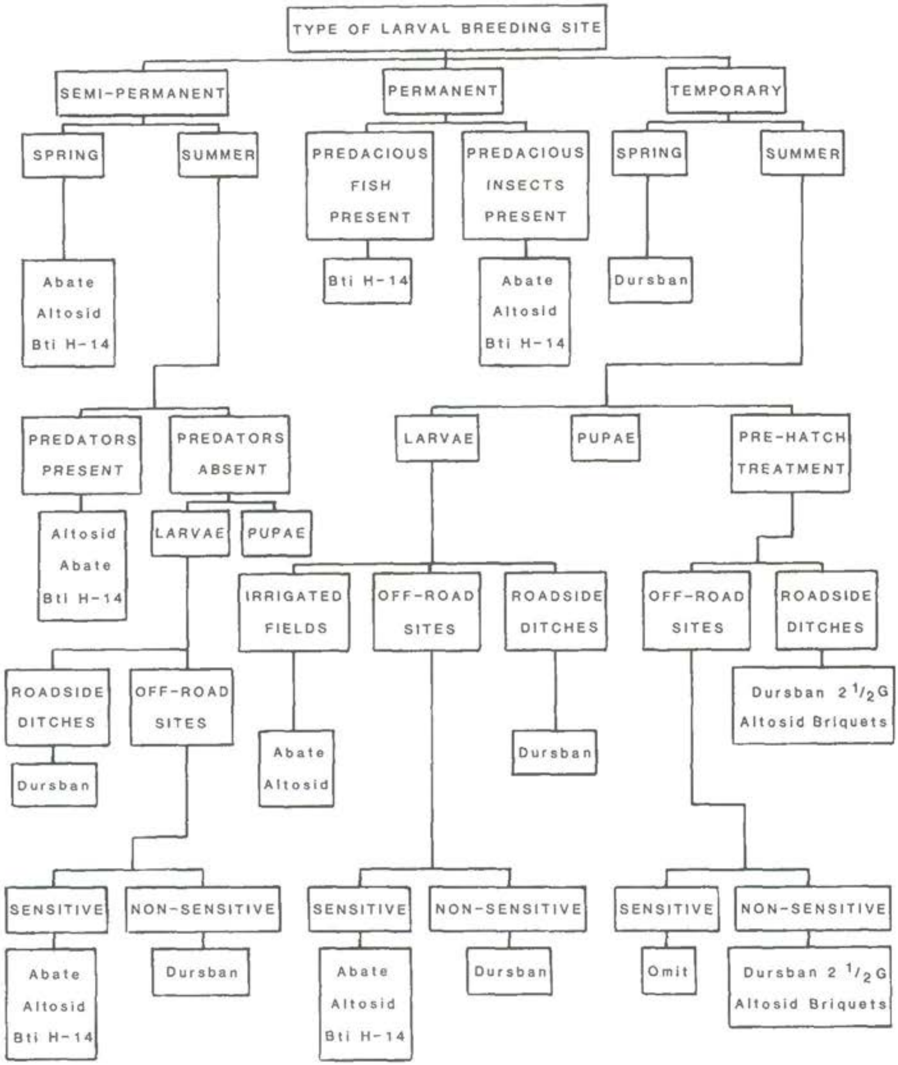

Figure 6 A guide to the selection of the appropriate larvicide for mosquito control. Adapted from Alberta Environment (1985)

the U.S.A. on mosquito control, is also experimenting with the use of Bti H-14 (Breeland and Mulrennan 1983).

The selection of the larvicide to be used for mosquito control will depend on the nature of the water body as well as the efficacy of the pesticide in relation to its cost and availability. Where the preservation of the ecological balance of the water body or the fish fauna is important, careful selection is necessary. An example of the choices available in the Canadian state of Alberta and recommended in the mosquito control training manual are illustrated in Figure 6 (Alberta Environment 1985).

3. Molluscicides

As with some aquatic insect larvae, certain aquatic snails are vectors of human disease, most notably schistosomiasis. Although snails often show a preference for still or slow-flowing waters they may occur in all types of water bodies. The creation of man-made lakes and fish ponds have provided additional breeding grounds for the snail host of schistosomiasis and the occasional flow of water via irrigation canals allows rapid and efficient spread of the snails (Balk and Koeman 1984).

3.1. Schistosomiasis control

The distribution of the parasitic worms causing schistosomiasis and their snail hosts is widespread in West Africa and also in other areas such as Brazil, Jordan, the Philippines and Egypt (Figure 7). Control of the disease, by control of the snail vector, has usually been achieved by combining chemotherapy and environmental and biological measures with the use of chemical pesticides or molluscicides in organized control projects (WHO 1985b). It is anticipated that the use of molluscicides will remain important to the adequate control of schistosomiasis in the future (McCullough, Gayral, Duncan and Christie 1980; WHO 1985b).

The use of molluscicides over large areas, such as in major irrigation schemes, can be effective in the control of schistosomiasis where human population density is high. However, the most effective method of control of the disease is to treat locally important transmission sites. These are often small water bodies with a limited seasonal significance. The application of molluscicides is, therefore, usually confined to seasonal applications to specific lakes, ponds and irrigation systems (McCullough et al. 1980). As transmission of the

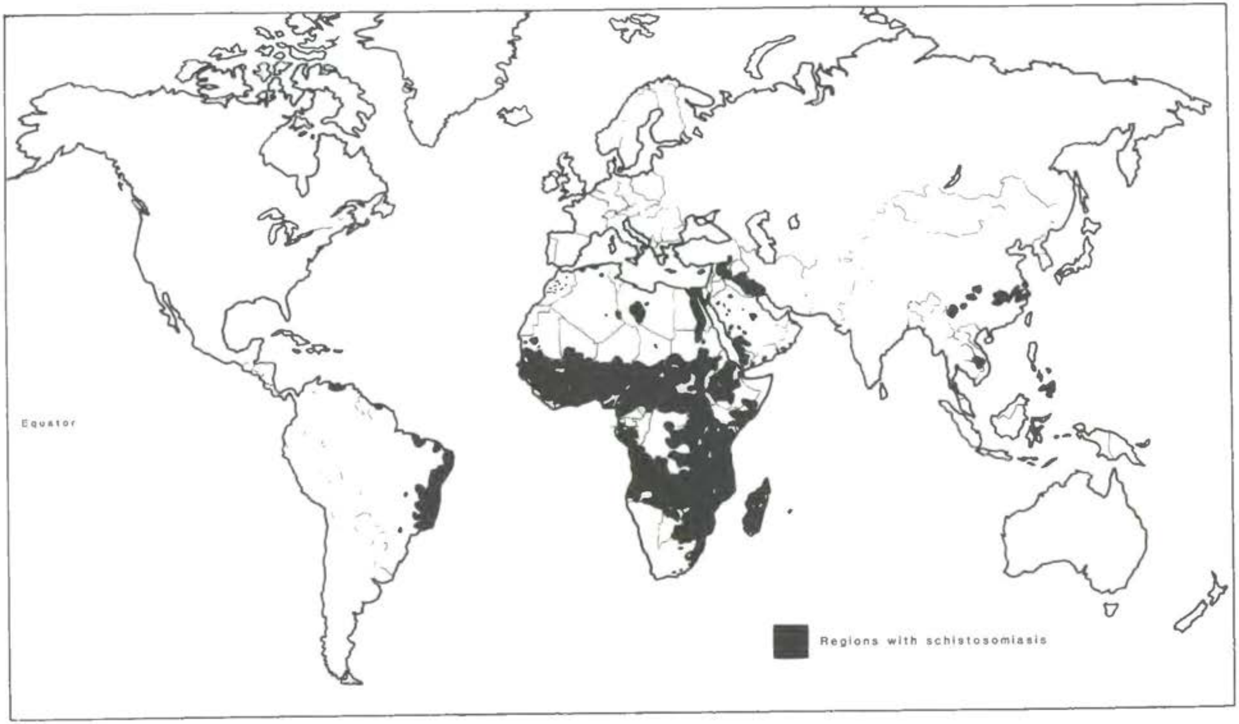

Figure 7 Global distribution of schistosomiasis. Adapted from WHO (1985b)

disease in tropical Africa usually takes place in the early and mid-main dry season, only three applications of molluscicide may be necessary each year - the first towards the end of the main rainy season after flooding has ceased, the second early in the main dry season and the last in the short dry season. The recent promotion of swamp rice development in West Africa (White, Coleman and Jupp 1982) and the expansion of rice irrigation schemes may also lead to additional requirements for the use of molluscicides in the future.

The apparently restricted demand for the use of chemical molluscicides has led to all but one being withdrawn from the general market (McCullough et al. 1980). Niclosamide is now the only synthetic chemical molluscicide routinely manufactured for sale as recommended by WHO (1985b). It is also known by its trade name of Bayluscide and a similar chemical in Egypt is known as Mollutox (WHO 1985b). However, niclosamide or its ethanolamine salt has been sold under various names besides the widely used Bayluscide, because it also has medical and veterinary uses for controlling tapeworm infections. A detailed discussion of the properties, biology and toxicology of niclosamide is available by Andrews, Thyssen and Lorke (1983).

Application of niclosamide to stagnant or small flowing water bodies is usually by means of spraying devices whereas larger flowing water bodies are treated by drip-feeding. The recommended application rate is 0.6-1 mg ℓ^{-1} water in flowing waters and 0.4-0.6 mg ℓ^{-1} in stagnant waters depending on the formulation used (Bayer AG 1970, Technical Information). For schistosomiasis control WHO (1973) recommends 0.6-1 mg ℓ^{-1} with an exposure time of 8 hours. In Iran Bayluscide had been applied once a year at 1.0 mg ℓ^{-1} for over 10 years resulting in some possible resistance within the snails (Jelnes 1977). For a similar period of use no evidence of resistance was found by Barnish and Prentice (1981) in Saint Lucia in the Caribbean where the common field dose was 0.33 mg ℓ^{-1} for 24 hours.

The effects of niclosamide on non-target organisms have been reviewed by Andrews et al. (1983) and it appears that at the concentrations used there is little effect on invertebrate fauna, but fish and amphibia may be severely affected. Aquatic vegetation impedes water flow and molluscicide dispersal and the use, therefore, of both a herbicide and a molluscicide may be necessary in some water bodies (Andrews et al. 1983).

The quantity of niclosamide used on a regional or national scale appears to be small when compared with the quantities of larvicides used. Egypt uses far more niclosamide than any other country which

Table 6 Quantities of niclosamide (metric tonnes of active ingredient) used for the control of schistosomiasis.

	Actual use		Estimated use				
Country/Region	1978	1979	1980	1981	1982	1983	1984
Africa							
Total	2.1	1.6	1.2	2.2	2.5	3.0	3.7
Eastern Mediterranean							
- Egypt	222	132	273	273	301	301	273
- Rest	3.8	3.8	7.4	7.5	7.0	6.5	5.5

Source Smith and Lossev (1981)

supplied data (Table 6) (Smith and Lossev 1981) and, together with China and Brazil, has the most prevalent occurrence of the disease in the world (Doumenge and Mott 1984). Molluscicides have been included in the control programmes for schistosomiasis of all three countries (WHO 1985b).

Other chemicals have been used as molluscicides in the past such as trifenmorph, sold commercially as Frescon(R). This molluscicide showed some unacceptable toxicity to fish and aquatic invertebrates (Duncan 1981) and is seldom used now. It is only manufactured if particularly requested (McCullough et al. 1980). Copper salts have also been used in the past but are no longer popular because they are relatively inefficient and proportionately more expensive than niclosamide (McCullough et al. 1980; WHO 1985b).

Possibilities for the use of new chemicals, such as nicotinanilide which shows promise as a selective molluscicide (Dunlop, Duncan and Ayrey 1980; Duncan and Brown 1983), are always being investigated. There is also much current interest in the development of organotins, particularly triorganotin compounds (Duncan 1980; McCullough et al. 1980). These appear to be effective in slow-release formulations enabling low doses to be achieved over prolonged periods (Cardarelli and Evans 1980), and in field trials the effects on non-target organisms appear to be negligible (Duncan 1980). However, they do not seem to be widely used at present.

3.2. Plant molluscicides

Some plants and plant substances can kill snails. These 'plant molluscicides' were originally discovered because they were efficient fish poisons (McCullough et al. 1980) and they are, therefore, generally harmful to the aquatic environment. However, there has been a revival of interest in the use of plant molluscicides as they have certain economic advantages. They grow in endemic areas and, therefore, using local plant species saves the cost of purchasing, importing or transporting chemicals. Another advantage is that rural communities can be encouraged to help themselves by growing the plants and applying them to schistosomiasis transmission sites (Duncan 1985). This approach is still in the experimental stage but represents a possible advancement in self-help within developing nations.

The best known plant molluscicide comes from the berries of Phytolacca dodecandra, otherwise known as endod. It has successfully been demonstrated as a suitable means of controlling schistosomiasis in northern Ethiopia (Duncan 1985) but unless grown and produced on a commercial scale, endod is only likely to be used in the localized areas where it is grown. It is very effective against planorbid snails and although it does not show any permanent harmful effects on most stream organisms it is lethal to fish (McCullough et al. 1980).

More recent interest has been focused on the plant Ambrosia maritima L. which grows in Egypt and the Sudan and which is known locally as damsissa. Although effective against snails as well as schistosomal miracidia and cercaria during field trials (El Sawy et al. 1983, 1984; Duncan 1985), its toxicity to other organisms at molluscicidal concentrations appears to be low (McCullough et al. 1980). However, very little research on the toxicity of Ambrosia, or other locally used plant molluscicides, has been carried out in the field and the effect of occasional use on the aquatic ecosystem is little known. Although there is information on which plant families contain molluscicidal agents (Kloos and McCullough 1982) extensive use of these plants is not foreseen in the very near future until more extensive research can be carried out on the toxicology of the most useful plant molluscicides (Duncan 1985).

4. Herbicides

Aquatic herbicides are used to control problems of excessive weed growth in, or at the edges of, almost any still or slow-flowing water body. The growth of aquatic vegetation can impair the use (and aesthetic quality) of a water body. The most serious problems with aquatic weeds occur in irrigation and drainage channels and navigable waters where they cause blockages and a reduction of the carrying capacity of the channels, leading to water shortages downstream and flooding upstream. The reduction of flow rates also leads to increased siltation, evaporation and seepage. It has been estimated that aquatic weeds have reduced flow in the irrigation canal system in India by 40 to 80 per cent (Gupta 1973). The Chambal Canal system was first affected by weeds within a year or two of being opened and within 10 years the discharge of the canals had been reduced by 60 per cent. This particular system, however, flows too fast to be treated with herbicides. The expansion of irrigation systems for agriculture has also necessitated herbicide use for aquatic weed control (Sarpe, Balan, Melachrinos and Florea 1974).

Other problems caused by weeds in ponds and lakes are concerned with a loss of commercial and recreational uses, such as fishing and boating. Large weed growths provide shelter for the food organisms of game fish whereas the decay of weeds under ice cover can lead to deoxygenation and fish deaths. If the lakes and ponds are used for water supply or irrigation the water intakes and sprinkler heads can become blocked. Additional weed growth also provides breeding grounds for insect pests including vectors of human disease, such as mosquitoes. Excessive algal growths can lead to deoxygenation when the algal bloom collapses and certain algal species can release toxins and impart taste and odour to the water. This is a particular problem within reservoirs providing water for human consumption (Moss 1980).

Man-made water bodies such as the lakes created by the damming of large rivers for electricity generation and irrigation occasionally suffer from rapid colonization of aquatic weeds. Examples include the growth of the fern Salvinia modesta D. S. Mitchell in Lake Kariba in East Africa and the water hyacinth Eichornia crassipes (Mart.) Solms-Laub at the Jebel Auliya dam on the River Nile in Sudan (Moss 1980). Within four years of completion of the dam at Lake Kariba Salvinia covered a quarter of the lake (1,000 km^2) and there was concern that it might cause problems for the turbines of the power station (Moss 1980). Fortunately the Salvinia growth declined naturally before it became necessary to use control methods.

As aquatic weeds may be free-floating plants, submerged or partly submerged plants or algal species, aquatic herbicides may be used within the water or sprayed onto emergent leaves of littoral or floating plants. As a result chemical herbicides are classified broadly into two groups, (a) the systemics which are absorbed by the plant and disrupt its physiology and (b) the contact herbicides which cause death on contact with the plant.

4.1. Aquatic uses

Although herbicides are used worldwide, they are often only used in response to a particular 'nuisance' event or perhaps once or twice a year to kill off a recurrent weed problem. Therefore, compared with large organized schemes of pest control, the quantities used on a national or regional basis are small. Apart from the authorities responsible for navigation, irrigation and water supply, herbicides are mostly used by individuals who obtain them from local distributors. Many of these herbicides are also used for both aquatic and terrestrial weed problems and records of quantities of herbicides used only in aquatic situations are very difficult to obtain, especially as once sold it is difficult to determine to what use the chemical has been put. Edwards (1986), using FAO data compiled from questionnaires returned by 38 countries in 1973, showed that herbicide use was only three per cent of the total pesticide consumption. However, the estimates for demand in developing countries suggested 30-40 per cent. In those countries where rice is a major food crop, such as the Philippines, this proportion is as high as 54 per cent (Morallo-Rejesus 1983). Rice cultivation represents a special form of aquatic environment and is therefore dealt with in a separate section of this report.

Robson and Barrett (1977) estimated that in 1977 there were probably no more than 20 chemicals used for aquatic weed control in the world and a more recent estimate (Barrett, personal communication) suggests 25 to 30. However, many of these would only be used to a minor extent. The chemicals that appear to be in most common use in lakes, ponds, canals and ditches are listed in Table 6 along with their recommended application rates. The most commonly used herbicides are probably diquat, 2,4-D and paraquat and some of these are used in combination, especially paraquat and diquat. The use of aquatic herbicides for weed control has been reviewed by Brooker and Edwards (1975). Although some residue and persistent toxicity problems may exist for certain chemicals the ecological effects of those used for bankside vegetation, such as 2,4-D, should be minimal. Risks from contamination due to run-off are reduced by strong cationic binding to soil. However, binding to clay particles also leads to accumulation in sediments although information concerning the rates of slow release from contaminated sediments is to some extent inadequate (Newbold 1975).

The most troublesome aquatic weed in the world is reputed to be the water hyacinth, Eichornia crassipes, and much research has been carried out on methods for control including the use of herbicides. Aboaba (1973) reported that the Chagres River and the Panama Canal have had problems with water hyacinth since the canal was being constructed. For rapid control of this weed 2,4-D has been used extensively worldwide at between 1.1 kg ha^{-1} and 30 kg ha^{-1} although the usual rates vary between 2.0 and 5.0 kg ha^{-1} (Gupta 1973; Julian 1984). Diquat has also been reported to be effective at 1.7 kg ha^{-1} especially where rapid desiccation is required and 2,4-D-sensitive ornamental plants occur (Gupta 1973). In India paraquat was also found to be useful, particularly when mixed with 2,4-D (Shibayama 1981). All these herbicides are also recommended for controlling a variety of macrophytes in still or slow-flowing waters. The usual field application rate of paraquat is 0.5-1 mg ℓ^{-1} and at this concentration there is very little or no toxicity to fish and invertebrates. This has led to its successful use in fisheries reservoirs (Brooker and Edwards 1973) and it is estimated by Svobodava (personal communication) that Czechoslovakia uses the equivalent of 1,250 kg per annum of paraquat in fish culture ponds alone. Diquat is used to a much smaller extent, approximately 160 kg per annum.

In Africa the fern Salvinia molesta Mitch. is rapidly colonizing freshwater bodies, such as Lake Naivasha in Kenya and is causing serious problems for some fisheries authorities (Kongere 1979). The use of paraquat has proved very effective in control but recolonization has rapidly occurred from swamp areas, making mechanical removal also necessary (Kongere 1979).

There are two chemicals which are frequently used to control algal growths in ponds, especially fish ponds and even swimming pools. These are simazine and copper, usually as copper sulphate. Simazine inhibits photosynthesis and is fairly persistent with a half life of 14-28 days at the active rate of 0.5 to 3.0 mg ℓ^{-1} (Aston and Reynaert 1974). It is also effective against submerged macrophytes at 1.0 mg ℓ^{-1} (Gorden, Waite, Tazik and Wiley 1982) and is reported to be used in India as an algicide (Gupta 1973). Copper sulphate is usually used at 0.1-1.0 mg ℓ^{-1} in fish ponds with frequent application each month if necessary. Build-up of copper in the ponds, especially in the sediment is not, however, usually a problem as fish ponds are often cleaned out several times a year (Bohl, Wagner and Hoffmann 1982). Early attempts to use copper sulphate for water weed control (Watson and Bollen 1952) showed that the effective concentration exceeded the safe limit for fish and fish food organisms. It is usually only recommended for use in non-potable water sources, although effective use at 0.5 mg ℓ^{-1} in a water supply reservoir in Taiwan has been described by Tseng and Wang (1986). Herbicides may also be used occasionally as part of a disease vector control programme. WHO (1984) recommends the use of certain herbicides on the aquatic habitats of the larvae of the mosquito Mansonia sp. (Table 7) to reduce their suitability as breeding sites.

4.2. Indirect effects of herbicide use

The quantities of herbicides used in the aquatic environment are small, especially when compared with the use of larvicides for major vector control programmes. Nevertheless the resultant effects on the ecosystems concerned are often much more serious and may be permanent (Robson and Barrett 1977). Although the chemicals may be fairly specific to the weed species concerned and, with the exception of copper and acrolein, not directly toxic to fish at normal application rates (Tooby 1976), the indirect effects on the ecosystem following the use of a herbicide are more important (Newbold 1975; Hellawell 1986). The most noticeable effect following the use of a herbicide is a decline in oxygen levels in the water due to the reduction or loss of the oxygen-producing weeds themselves and a further reduction as a result of the oxygen demand created by the decomposition of the dead weeds. Use of simazine at 1.0 mg ℓ^{-1} in a pond in the U.S.A. totally eliminated submerged macrophytes (Gorden et al. 1982) and resulted in a decrease in daytime dissolved oxygen levels from 8.0 mg ℓ^{-1} to 3.0 mg ℓ^{-1} within three days. Although the levels recovered to 5-6 mg ℓ^{-1} by the seventh day after

Table 7 Herbicides used in control of the mosquito larva Mansonia sp.

Herbicide	Application rate	Weed species
Diquat	0.45 ℓ m^{-2}	Eichornia
2,4-D	400 ℓ ha^{-1}	Salvinia, Pistia
Amitrole	1.1-22 kg ha^{-1}	Scirpus
Dalapon	5.5-55 kg ha^{-1}	Scirpus
MCPA	700 g ha^{-1}	Pistia

Source WHO (1984)

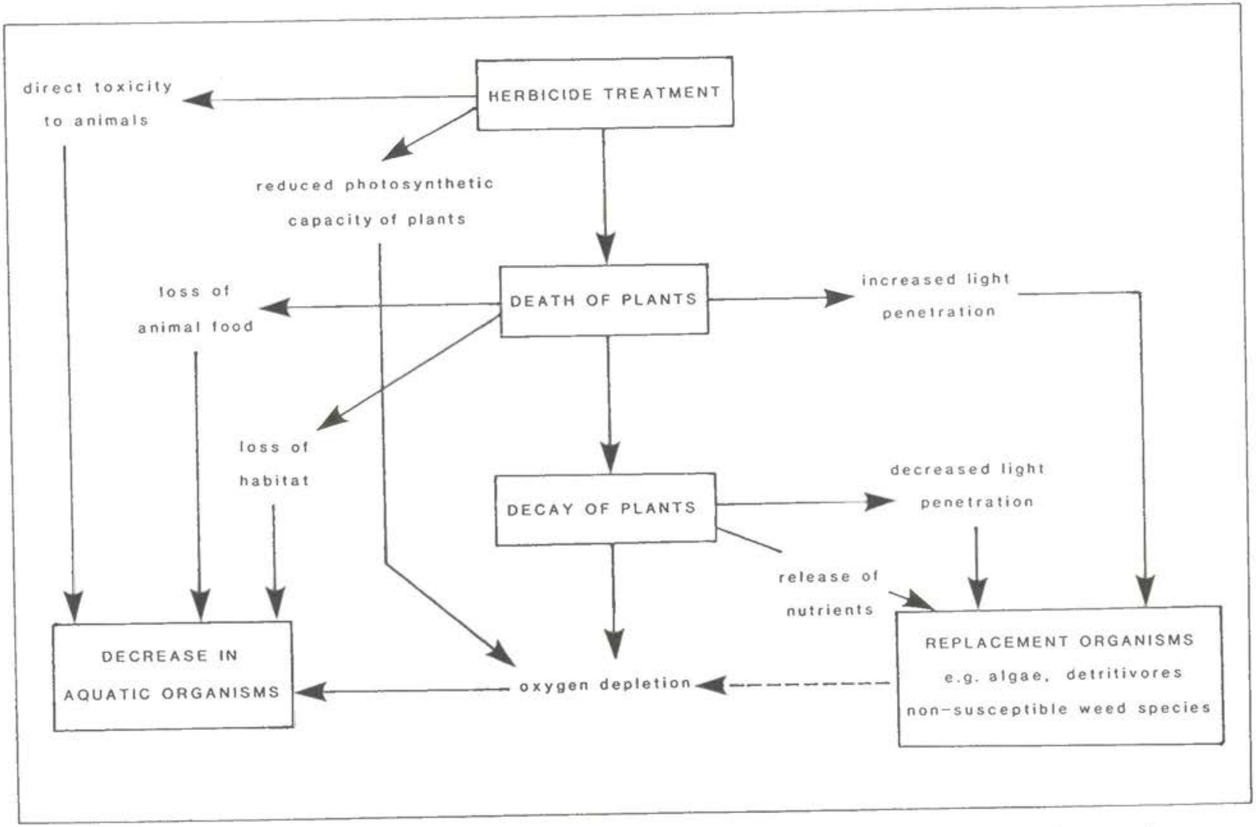

Figure 8 Some environmental effects of herbicide treatment of aquatic weeds

treatment, these levels were low compared with a control pond. Simazine is, however, reported by Aston and Reynaert (1974) to kill weeds more slowly than other herbicides resulting in a less marked oxygen depletion. A discussion of the effects of herbicides on aquatic systems is available in Newbold (1975) together with some detailed information on selected chemicals.

Reduced oxygen levels may result in the death of fish by suffocation or an increase in respiration rate leading to increased accumulation of the herbicide and a decline in fish growth and fish yield (Tooby 1976). This can also be caused or aggravated by changes in the invertebrate populations on which they feed, brought about by a loss of refuge in the weeds, loss of food source such as planktonic or epiphytic algae (Gorden et al. 1982) or changes in the chemistry of the water (Murphy, Hanbury and Eaton 1981). Many fish relying on the weeds for refuge (especially juveniles) and for reproduction (Brooker and Edwards 1975) will also be affected. The environmental effects of herbicide treatment can be summarized by Figure 8.

Many herbicides need to be applied at certain stages of the growth of the weed in order to be most effective; for example diquat, which is recommended to be used when plants are actively growing and when water temperatures are 18°C or above at dawn, dusk or on an overcast day (Alberta Environment undated). Ideally these factors should be considered along with the resultant disruption of the ecosystem in order to produce minimal environmental effects.

5. Piscicides

Historically fish poisons or piscicides were used to kill fish in large numbers for food whereas today chemicals are also used to manage fisheries containing unwanted or nuisance species, particularly in game and sport fisheries.

5.1. Lamprey control

Although the use of piscicides is negligible compared with other pesticide use, there is a programme of extensive use of TFM in the North American Great Lakes. This chemical is used to control the sea lamprey, Petromyzon marinus Linnaeus, which is a parasite of the trout in that area. The lake trout forms the basis of an important fishing industry in the Great Lakes. The larvae of the lamprey live in more than 400 of the feeder streams of the lakes and can be effectively treated with TFM between May and October (NRCC

1985). As the larvae spend four to seven years in the streams, several year classes can be eliminated with one treatment. This reduces the number of streams that have to be treated each year (NRCC 1985). Between 1958 and 1983, 1,656 treatments were made of 386 different streams feeding the Great Lakes as part of the Sea Lamprey Control Programme. This resulted in a total of 1,264.6 tonnes of TFM being applied over those years. It has also been found that TFM is more effective when small quantities of Bayer 73 (the molluscicide niclosamide) are added to the mixture (Howell, King, Smith and Hanson 1964), and over the same period 8.4 tonnes of Bayer 73 were also used.

An extensive review of the environmental behaviour of TFM and Bayer 73 when used as lampricides, together with their toxicity and effects on non-target fauna and flora, has been carried out by NRCC (1985). After TFM treatment a reduction in invertebrate populations may be observed but it has been suggested that this may be mostly due to increased downstream drift (Dermott and Spence 1984). Aquatic annelids have been observed to be particularly sensitive to TFM (NRCC 1985; Jeffrey et al. 1986) as have some mayflies (Bills, Marking and Rach 1985; NRCC 1985). The effects on other invertebrates may be related to the hardness of the water (Dermott and Spence 1984; NRCC 1985). As the streams are treated infrequently with TFM and the invertebrate fauna is only mildly affected, the ecosystems rapidly recover and the disruption is apparently minimal (NRCC 1985).

5.2. Other uses

Other chemicals used occasionally as piscicides include rotenone, toxaphene and antimycin. Rotenone is extracted from the plant Derris in Asia and Lonchocarpus in South America. It is the oldest fish poison that has been used to collect fish for food. It breaks down rapidly in the environment and at concentrations used to kill fish causes little mortality or disruption to non-target fauna except for some microcrustaceans (Hellawell 1986). It has been used in the Scottish freshwater lochs at 0.04-0.06 mg ℓ^{-1} causing some mortalities, but the invertebrate communities may recover rapidly depending on the timing of the application in the life cycle of the organisms (Morrison and Struthers 1975). When used in streams it also caused some drift and mortalities but invertebrate populations recovered within a year (Morrison 1977).

Toxaphene, a chlorinated camphene insecticide, has been used in the U.S.A. as a substitute for rotenone (Hellawell 1986). At the concentrations required to control large and small fish (0.1 mg ℓ^{-1}) toxaphene results in severe residual toxicity for two to 12 months, preventing restocking. It is, therefore, restricted in its use (Hellawell 1986).

Antimycin is an antibiotic which is highly toxic to fish but enables some selective control of unwanted fish species because different species have different susceptibilities. It has been used successfully at 10 µg ℓ^{-1} to control trout populations in streams in Scotland. The effects on invertebrates were minimal with a decline in only two species (Morrison 1979).

Where piscicides are used to remove unwanted fish species their use is carefully controlled. However, the use of fish poisons to gather fish for food is normal practice for some villagers particularly in developing countries. Whereas this used to be carried out with rotenone, which is relatively harmless to the environment, the acute toxicity of some modern chemical pesticides is now being exploited. Documented studies are few but this practice is occasionally reported by eye witnesses. Deliberate use of endosulfan and lindane has been recorded in the Lake Kinneret watershed in Israel (Wynne 1986) and of Gammalin-20 in Nigeria (Victor and Ogbeibu 1986). Gammalin-20 is a commercial formulation containing 200 g ℓ^{-1} lindane. As a result of increased inspection of fish catches and the eventual prosecution of offenders there has been a decline in the use of pesticides for fishing in the Kinneret region since 1984 (Wynne 1986). However, in Nigeria the indiscriminate use of Gammalin-20 is reported to be increasing and it is suspected that the quantities used for each fish kill are large (Victor and Ogbeibu 1986). The destruction of the communities within the ponds and river channels receiving the Gammalin-20 is extensive. Victor and Ogbeibu (1986) observed loss of macrophytes within two days of treatment, and after 17 days not a single fish could be found in the treated pool. Many invertebrates disappeared completely and although recolonization did occur, several groups of organisms were still not represented after three months.

Such indiscriminate and deliberate use of pesticides will probably result in severe disruption of aquatic ecosystems in those regions of the world where this practice is increasing, especially where the same areas of rivers or ponds are treated repeatedly.

6. Pesticide use on flooded rice

Rice is one of the most important cereal food crops in the world and is the staple food of millions of people (COPR 1982). With the growing need for world food supplies rice production has increased rapidly. In 1975 the world production of paddy rice (flooded rice) was 348,570 thousand tonnes from 142,085 thousand hectares whereas in 1985 465,970 thousand tonnes were produced from 144,674 thousand hectares (FAO 1977, 1986). Paddy rice spends some, or all, of its growth period in flooded fields. Therefore, although artificially created, paddies represent temporary water bodies controlled by irrigation systems which probably connect with other more permanent aquatic systems such as rivers, lakes and ponds. Upland rice, which relies on rainfall for the necessary water supply, is less common although in some areas such as Central and South America the proportion of upland rice may vary from 2 to 58 per cent of the total production. At 58 per cent Brazil is reported to have the largest extension of upland rice in the world (CIAT 1986).

There is a very large number of pests and weeds associated with rice and many of these are widespread and common in many rice-growing nations (COPR 1982). In Malaysia there are 159 species of insect pests recorded in rice paddies, 12 of which are of economic importance (Yunus and Soon 1971) and in Taiwan 142 weed species are recorded, 25 of which are major weeds (COPR 1982). Fungal diseases are also a problem in rice cultivation. Although chemical treatment was not widely practised in the past (COPR 1982), in Central and South America there is now excessive and inadvisable use of fungicides (CIAT 1986). There is also an increasing development and use of antibiotics against fungal diseases (COPR 1982).

6.1. Growth in the use of pesticides

The estimated rice crop losses due to pests are as high as 57 per cent in Asia but only 28 per cent and 36 per cent in South America and Africa respectively (Edwards 1986), and in some areas of the world rice is responsible for the major use of pesticides. In the Philippines, between 27 and 90 per cent of certain pesticides are used on rice (Table 8) and 54 per cent of all herbicides (Morallo-Rejesus 1983), and in Taiwan 29.9 per cent of all pesticides are used on rice (Chu and Lin 1983). The importance of the rice crop has led to increased pesticide use, and even in 1971 90 per cent of farmers in Malaysia were using insecticides on rice (Yunus and Soon 1971). It was reported by Chu and Lin (1983) that in 1981 the annual consumption of insecticides and fungicides in paddy fields in Taiwan was approximately 8,419 tonnes and 2,481 tonnes of formulated products respectively. Thus it would appear that rice paddies will continue to

Table 8 The percentage of total annual consumption of selected pesticides used on rice cultivation in the Philippines

Pesticide	1979 %	1980 %	1981 %
Azinphos-ethyl	60.05	60.00	55.00
BPMC	60.00	90.02	90.01
Carbofuran	63.96	34.38	27.58
Endosulfan	89.91	90.00	90.00

Source Morallo-Rejesus (1983)

be a major source of agricultural pesticides into aquatic environments around the world. Although other control measures for rice pests, such as integrated pest management (IPM) techniques (Falcon and Smith 1979; Lim and Heong 1984) which are constantly under development are available, their use needs further promotion (Lim and Heong 1984). As insecticides have a proven record of increasing rice yield their use is predicted to increase, especially within countries of the Far East region, such as Japan, Taiwan, China, Indonesia, the Philippines and Thailand (Ishikura 1984).

6.2. Environmental constraints

Paddy fields may be included in a crop rotation or they may be allowed to spend some of the year fallow. However, some 'permanent' paddy ecosystems exist in areas where rice has been planted annually on the same land for centuries, such as in India (COPR 1982). In these areas it can be expected that the irrigation system and any associated water bodies will be repeatedly subjected to pesticides and herbicides, mostly as residues remaining in the paddy irrigation waters or from run-off and indirect inputs from spraying activities to the emergent rice plants. The effects on the irrigation channels, ditches, canals and rivers may be important if they contain food organisms such as fish, shellfish or amphibians.

In some areas, particularly South-East Asia, the temporary water bodies created by flooded rice are used to culture fish, which form an important source of animal protein. This dual culture system was once widely practised but is believed to have declined with the increase in sea fishing and the widespread use of various pesticides on rice (Huat and Tan 1980; Koesoemadinata 1980). Nevertheless, Huat and Tan (1980) estimated that 14 per cent of the area cultivated for rice in Malaysia and 11 per cent of that in Japan were being used for fish production also. Consequently the effects of some of the most commonly used rice pesticides on fish have been investigated (Yunus and Soon 1971; Moulton 1974; Davey, Meisch and Carter 1976; Estores, Laigo and Adordionisio 1980).

It is believed that properly managed fish culture can eliminate weeds, molluscs and mosquitoes in the rice fields (Singh, Early and Wickham 1980). In South-East Asia the most popular method is to allow the wild fish from the irrigation channels into the paddies; this requires no special effort. However, alternative stocking methods may be used, rearing the fish with the rice crop or in rotation. Both methods which allow fish culture during the growth period of the rice are not really compatible with pesticide use (Huat and Tan 1980). In the U.S.A. fish may be encouraged in paddy fields to assist with the control of mosquito larvae (Davey et al. 1976; Flickinger, King, Stout and Mohn 1980).

6.3. Insecticides used on rice

Many chemicals are suitable for the control of several insect pests, the most important of which are summarized in Table 9. Although DDT, endosulfan, BHC (HCH) and parathion have all been widely used in the past (Yunus and Soon 1971; Balasubramaniam 1976; Davey et al. 1976; Sethunathan, Siddaramappa, Siddarame Gowda and Rajaram 1976; Ishikura 1984) only endosulfan is still reported to be widely used or recommended in recent years particularly in South-East Asia (Lee and Ong 1983; Morallo-Rejesus 1983; Soekarna and Sundaru 1983). Asia has 90 per cent of the world total land area used for paddy rice cultivation (Table 10) and within Asia, India and China are the major rice producers (Table 11). Pesticides favoured by these and other Asian countries (Table 12) are probably the most widely used on rice. Many of these pesticides are amongst those reported as the most frequently used in Latin America also (Table 13). Endosulfan is used selectively due to its acute toxicity to paddy fish although no fish mortalities were observed in connecting ponds and irrigation channels by Yunus and Soon (1971). BHC and DDT have become unpopular since the recognized persistence of some organochlorine compounds led to their being banned from use in many countries. Where concurrent fish cultivation is important less toxic pesticides such as the carbamates are being used, particularly carbofuran which is the only recommended pesticide for rice-fish culture in the Philippines (Estores et al. 1980).

Table 9 · Major rice pests and the recommended pesticide (COPR 1982)

Pesticide	Stem borers	Grass-hoppers	Leaf-hoppers	Plant-hoppers	Delph-acids	Bugs	Stink bugs	Thrips	Leaf rollers	Green cater-pillars	Jap. leaf minor	Leaf minors	Hispas	Leaf beetles	Mealy-bugs	Gall midge
Acephate	x		x	x		x	x									
Aceph.+ Carbaryl			x													
Allyxycarb			x	x	x											
Azinphos-methyl	x		x			x	x	x	x					x		x
BHC	x			x									x			
BHC + Carbaryl			x													
BHC + Isoprocarb			x	x												
BHC + MTMC				x	x											
BPMC			x	x												
Bufencarb				x												
Carbaryl			x	x				x	x							
Carbofuran	x		x	x												x
Carbophenothion				x												
Cartap	x								x	x	x	x		x		
Cartap + BPMC			x													
Chlordimeform	x		x	x					x							
Chlorfenvinphos	x			x		x										
Chlorpyrifos	x		x		x											
Cyanofenphos	x															
DDT	x	x												x		
Demeton-S-methyl			x	x	x											
Diazinon	x	x	x	x				x				x	x		x	x
Diaz.+ BPMC				x												
Diaz.+ MTMC				x												
Dichlorvos		x		x	x	x	x		x		x	x	x		x	
Dicrotophos	x		x	x	x	x							x			
Dimethoate			x						x						x	
Disulfoton	x		x	x												
Endosulfan			x	x												
EPN											x					
Ethyl DDD				x												

Fenitrothion	x		x							x		x	x	x		
Fenit.+ BPMC				x												
Fenit.+ Cyanof.																x
Fenit.+ Malath.	x		x	x	x			x		x						
Fenit.+ MPMC			x	x												
Fensulfothion	x															
Fenthion	x	x	x	x		x	x	x			x	x	x	x		
Formothion	x								x							
Form.+ Disulfoton			x													
Isoprocarb			x	x												
Isothioate			x	x												
Leptophos												x				
Malathion	x		x	x	x	x		x	x							
Mephosfolan	x		x										x			x
Methomyl			x											x		
Monocrotophos	x			x		x	x		x							
MPMC				x												
MTMC				x		x										
MTMC + Chlordim.				x												
Naled			x	x												
Oxdemeton-methyl			x	x	x											
Phenthoate						x				x						
Phorate			x	x				x				x			x	x
Phosmet	x		x	x							x		x	x	x	x
Phosphamidon	x	x	x										x			x
Propaphos				x												
Propoxur				x												
Pyridaphenthion	x													x		
Salithion	x															x
SD 8280			x			x	x									
Triazophos			x													
Trichlorfon	x										x	x		x		
XMC				x												

6.4. Herbicides used on rice

Rice paddies may be treated with herbicides to remove unwanted weed species before rice planting, during the germination period and during rice growth depending on the method of rice cultivation used (COPR 1982). Significant growth in the use of herbicides on rice in Asia has been reported for several countries. In Taiwan there has been a growth from 1.4 per cent of the total acreage treated in 1969 to 91.2 per cent in 1979 (Chiang and Leu 1981). Korea was treating 75 per cent of the paddy fields in 1980 and this was estimated by Kim (1981) to increase to 150 per cent over the following 10 years. This means that at least half of the paddy acreage would receive two applications each year. Japan is reported to be treating 200 per cent of the total rice acreage, i.e. all rice fields are treated twice with herbicides (Chisaka 1983) and between 9 per cent and 31 per cent of rice fields receive three or four applications (Kusanagi 1981). De Datta (1981) reported that in the Philippines 1.2 million hectares were treated in the wet season and 0.8 million hectares in the dry season. Use of herbicides for weed control in rice was predicted to increase in Malaysia, whereas Thailand and Bangladesh will probably rely more on hand weeding (De Datta 1981).

Herbicides widely used before seeding or transplanting are dalapon, paraquat and glyphosate and those commonly used on rice after planting are 2,4-D, MCPA, butachlor, nitrofen, benthiocarb and molinate (COPR 1982). The most commonly used herbicide in South and South-East Asia together is 2,4-D (De Datta 1981) and although Thailand uses very little herbicide the most common chemical is also 2,4-D (Teerawatsakul 1981). However, in Korea the most popular herbicides are butachlor and nitrofen (Kim 1981). Based on the recommended minimum application rates (COPR 1982) and the estimated world cultivated area of paddy rice in 1985 (FAO 1986), and assuming that each third of this land is treated only once a year with one of the herbicides, the annual use of paraquat, dalapon and glyphosate on rice alone would be approximately 24,000 tonnes (a.i.) of paraquat, 145,000 tonnes (a.i.) of dalapon and 48,000 (a.i.) tonnes of glyphosate respectively.

If only half of the rice paddy area in the world is treated with a low dose of 2,4-D this would amount to approximately 36,000 tonnes of active ingredient entering aquatic systems in each rice growing season. It is generally believed that the toxicity of herbicides, especially those used in aquatic weed control, is low for non-target fauna. However, there is very little knowledge of the possible effects of long-term or repeated exposures and the possible chronic

Table 10 Land area used for rice cultivation by the major world regions

Region	Area 1,000 ha	% of total
Africa	5,467	4.0
North Central America	1,914	1.0
South America	6,122	4.0
Asia	129,977	90.0
Europe	388	0.3
Oceania	140	0.1
U.S.S.R.	667	0.5

Source FAO (1986)

Table 11 Rice acreage and production within selected Asian countries

Country	% of total acreage in Asia	% of total * production in Asia
Bangladesh	8.0	5.1
Burma	3.7	3.6
China	24.7	40.1
India	32.3	21.4
Indonesia	7.3	9.0
Japan	1.8	3.4
Kampuchea DM	1.3	0.4
Korea Rep.	1.0	1.8
Laos	0.5	0.3
Malaysia	0.5	0.4
Nepal	1.1	0.7
Pakistan	1.5	1.1
Philippines	2.6	1.9
Sri Lanka	0.7	0.6
Thailand	7.4	4.6
Viet Nam	4.4	3.7

* Mostly estimated data

Source FAO (1986)

effects on aquatic organisms. 2,4-D is reported to be biodegraded by microbial organisms and by photochemical action but it can take up to 35 days to disappear from water and mud (Brooker and Edwards 1975; Hellawell 1986)

The usual indirect effects on the aquatic ecosystems resulting from the use of herbicides (described in an earlier section) are unlikely to affect the rice paddy ecosystem too seriously because as shallow-water, temporary or man-made ecosystems they may not

Table 12 Pesticides used on rice by selected Asian countries

Pesticide	Japan (1)	Philippines (2)	Indonesia (3)	Taiwan (4)	Malaysia (5)
Acephate				x	x
Azinphos-methyl		x			
BHC					x
BPMC		x		x	x
Carbaryl	x		x	x	x
Carbofuran		x	x		x
Cartap	x			x	
Chlorpyrifos			x	x	
CPMC	x			x	
Cyanofenphos				x	
Diazinon	x	x		x	x
Dichlorvos				x	
Dimethoate				x	x
Disulfoton				x	
Diflonip				x	
Endosulfan		x	x		x
EPN	x			x	
Ethoprophos				x	
Fenitrothion	x		x	x	
Fenthion	x		x	x	
Malathion				x	x
Mephosfolan				x	
MIPC				x	
Monocrotophos		x	x	x	
MPMC	x				
MTMC				x	x
Phenthoate	x		x	x	x
Phosmet				x	
Propoxur	x			x	x
Triazophos			x		
Trichlorphon	x				

Sources (1) Ishikura (1984)
(2) Morallo-Rejesus (1983)
(3) Soekarna and Sundaru (1983)
(4) Chu and Lin (1983)
(5) Lee and Ong (1983)

Table 13 Insecticides used most frequently on rice in Latin America

Insecticide	Soil pests	Foliage pests	Panicle pests
Carbaryl		x	x
Carbofuran	x	x	
Chlorpyrifos	x	x	
Deltamethrin		x	
Dimethoate		x	
Heptachlor	x		
Malathion		x	
Metamidophos			x
Monocrotophos		x	x
Parathion			x
Phoxim		x	x
Trichlorphon		x	x

Source Data supplied by CIAT from their Annual Report 1986

establish a great diversity of organisms. Many of the invertebrates will be fast-breeding organisms with short life cycles and therefore able to adapt to change. Only those fish already tolerant of low oxygen levels will survive in paddy fields and therefore they may not be affected by the loss of dissolved oxygen caused by loss or degradation of weeds. However, those herbicides draining into the irrigation systems may cause problems in the channels, ponds and rivers as a result of macrophyte or algal death and decay.

7. Discussion

In gathering the information for this review it became clear that there is a lack of readily-available, accurate, up-to-date information on the quantities of pesticides manufactured, sold and used worldwide (OECD 1986). This problem stems partly from the manufacturers' unwillingness to release information and partly from a lack of adequate registration and recording procedures for pesticides within individual countries (Edwards 1986). This is a particular problem in some developing countries where the production of pesticides is increasing rapidly, although at present this largely consists of formulation of the active ingredients and subsequent packaging (Edwards 1986). It is also reported that foreign manufacturers market chemicals otherwise banned for use in the developed world (SAM 1984; Sattaur 1987).

Inadequately packaged or repackaged pesticides are reported to be common in developing countries (Sattaur 1987) and with poor labelling and instructions it is possible that many chemicals will be inappropriately used, contributing to uncontrolled environmental damage. Although the environmental effects of such misuse are generally localized, the more global implications of the cumulative effects of some pesticides are yet to be assessed.

Despite the global accumulation of DDT residues in animals and human tissues during its widespread use from the early 1940s to the early 1950s and its later ban from many countries, it is still in extensive use in certain developing countries (SAM 1984). Other persistent compounds such as endosulfan and lindane are also still applied to rice in South-East Asia and enter aquatic systems with the paddy field irrigation networks. These chemicals are extremely toxic to fish and whilst increasing the production of the rice crop they may be reducing the availability and stock of fish also used for food.

The continued use of some prohibited pesticides is occasionally revealed by the detection of residues during monitoring programmes of food products (Snell and Nicol 1986) and the environment (e.g. Wynne 1986). Unfortunately there are few national and international monitoring programmes which investigate pesticide residues in the freshwater environment. Existing programmes tend to be in the developed regions of the world such as those organized by the United States National Pesticide Monitoring Program (Schmitt, Zajicek and Ribick 1985) and the Organisation for Economic Co-operation and Development (OECD 1980). The Global Environment Monitoring System (GEMS) includes health-orientated monitoring of surface waters worldwide (GEMS/Water) organized by WHO, UNEP (United Nations Environment Programme), UNESCO (United Nations Educational, Scientific and Cultural Organization) and WMO (World Meteorological Organization). However, the data collected to date show that few developing countries, especially Africa, have succeeded in including pesticide residues in their regular monitoring. This is thought to be due to a lack of appropriate instrumentation (Barabas 1986). Pesticide monitoring is important not only for consideration of human health risks but also to enable identification of trends in the occurrence of pesticides in major water bodies and to identify the extent of global transport of some of these chemicals. Local schemes may help highlight indiscriminate or unauthorized use of persistent chemicals. The future activities of GEMS/Water may help to strengthen these monitoring activities in the developing areas of the world (WHO 1983). However, comprehensive pesticide monitoring schemes are extremely expensive and are, therefore, only recommended in water bodies suspected of being at risk from contamination, particularly if the water is to be used for human consumption (OECD 1986).

The urgent requirement for more food and better health in the developing world can result in a reduced priority for preservation of the environment. It is, nevertheless, important to conserve natural ecosystems. Aquatic environments particularly in developing countries are a major source of food, i.e. fish and shellfish, and drinking water, and maintainance of these resources is essential. Organized schemes of pesticide use such as the Onchocerciasis Control Programme (WHO 1985a) have taken into consideration the effect on the environment of the extensive application of pesticides and have chosen the chemicals and their application rates appropriately. The OCP is also carefully managed and co-ordinated and includes extensive regular monitoring of the treated rivers and the incidence of river blindness in the local populations (WHO 1985a). Thus the success of the pesticide use is being carefully judged and the application of the pesticides regulated accordingly. WHO (1985a) reports that the disease has been brought under control within 90 per cent of the programme area in the six to eight years that the programme has been running. This programme illustrates how pesticides can be used in the aquatic environment with great success and with minimum environmental effects.

Unfortunately the control of pesticide use in agriculture is not as easily regulated as within a major scheme such as the OCP. However, as has been illustrated within the Lake Kinneret watershed, the agricultural sources of pesticides are not a hazard especially when compared with other inputs (Wynne 1986). Nevertheless if regulation and control are not introduced into countries where they are currently lacking or inadequate, and where pesticide use is rapidly increasing, aquatic ecosystems may become threatened by agricultural run-off. It would be preferable to promote better education into the judicious and effective use of pesticides, and to enforce legislation and regulations now, before problems arise. This is perhaps particularly true for the use of pesticides on rice where small farmers may be using large quantities of pesticides in an attempt to obtain better yields, when mechanical methods or other approaches, such as the use of pest-resistant varieties, may work just as well.

Flooded rice ecosystems are a permanent feature of some developing countries and rice cultivation accounts for a large proportion of the pesticides used in certain areas of the world (Morallo-Rejesus 1983). A substantial number of chemicals may be applied to flooded rice (Tables 9, 12, 13) and some, for example endosulfan, would not be desirable for use in or near water bodies used to supply fish for human consumption, or permitted within countries where the regulation and control of pesticides is strictly enforced. Fortunately, however, the trends indicate that the less persistent organophosphate and carbamate pesticides are now increasingly used (Ishikura 1984). In order to ascertain whether the irrigation channels, rivers, streams and ponds associated with the rice paddies are suffering from the increasing use of pesticides on the rice crop some extensive monitoring programmes would be needed. These would be most appropriately carried out at the national level or perhaps within specific research projects to determine the extent of contamination of water bodies by run-off from rice paddies.

Herbicides are widely used in agriculture but their use in aquatic situations is limited. However, where they are used to control the water hyacinth and weeds of flooded rice they present a possible environmental risk to tropical water bodies. The resulting environmental damage could be severe, especially as herbicides are designed to be toxic to the primary producers of the ecosystem. Many herbicides are toxic to aquatic life and persistent in the environment and although not recommended for use near water bodies, accidental spillages or inadvertent spraying onto ponds and rivers can cause damage to freshwater ecosystems. The increase in use of herbicides in recent years, particularly on rice (e.g. De Datta 1981; Kim 1981), suggests more care may be necessary in enforcing appropriate use and application of these chemicals in the future in order to preserve the ecological balance of many aquatic systems. However, herbicide use on rice could be reduced if careful planting and management of the crop were encouraged (COPR 1982) so that high yields could still be obtained without frequent applications of broad-spectrum herbicides. The principles and methods of Integrated Pest Management should be promoted so that rice farmers may be encouraged to reduce the use of herbicides.

The need for more selective and less harmful pesticides results in a marketed product which requires more development and testing and is, therefore, likely to be more expensive. Consequently poorer countries are restricted to buying and using the cheaper, possibly more environmentally damaging but equally effective chemicals. For large public health schemes such as the OCP, international funding enables the most appropriate pesticide to be used (Galaydh 1986). If regulations concerning distribution and sale of the environmentally unacceptable chemicals are to be introduced, national efforts promoting the alternatives to pesticides must also take place.

Farmers in particular must be alerted to the environmental problems associated with pesticide use. They must also continue to produce as high a yield as possible for as small a financial outlay as necessary but with the minimum of environmental damage. For public health schemes consideration of the possible environmental effects of the chemical will probably remain less important than the choice of an efficient pesticide.

8. Conclusions

The major sources of pesticides into the aquatic environment, especially in the tropical regions and the developing countries, are larvicides used in public health programmes and possibly pesticides used on flooded rice fields. In most developed regions of the world pesticide use is controlled and apart from the use of herbicides few chemicals are extensively applied to water bodies. The risk to aquatic ecosystems in developed countries may, therefore, stem primarily from agricultural run-off and accidental spillages.

Concern for environmental effects has already led to a shift towards the use of the less persistent organophosphate and carbamate pesticides in place of the organochlorines. The widest use of organochlorines posing a risk to the aquatic environment appears to be the use of endosulfan and BHC (HCH) compounds on rice and the illegal use of these chemicals as fish toxins for fishing purposes.

At present there is little evidence of any serious disturbance of aquatic ecosystems resulting from the major programmes of pesticide use such as the blackfly control programmes in West Africa. However, the development of pesticide resistance in the blackfly has led to an increasing number of chemicals being employed, some of which present a greater environmental risk than the originally chosen organophosphate pesticide, temephos. This programme includes extensive monitoring of the environmental effects of the regular pesticide applications and therefore helps reduce the risk of environmental damage.

More effective monitoring programmes for pesticide residues in fresh water and freshwater fauna are necessary, especially in the developing regions of the world, in order to ascertain whether aquatic ecosystems are currently threatened by pesticide residues in agricultural run-off or inappropriate pesticide disposal.

Herbicides are becoming more widely used in agriculture all over the world. The risks to aquatic ecosystems can be quite severe when herbicides are sprayed directly onto water bodies either intentionally or accidentally, resulting in the destruction of the aquatic plants which are the primary producers of the ecosystem.

In order to prevent future damage to aquatic ecosystems, particularly within developing countries, from illegal, excessive or unnecessary application of pesticides there is a need for improved regulation and control of the chemicals manufactured, sold and used. When combined with an extensive programme of education and public awareness into the use and misuse of pesticides and the promotion of alternatives, these measures may enable food production levels to be maintained without undue risk to the aquatic environment.

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APPENDIX Pesticides referred to in the text

Common name	Trade names (1)	Uses (cited in text) (2)	C. A. Registry No.
Insecticides			
Acephate	Orthene, Ortran	R	30560-19-1
Allyxycarb	Hydrol	R	6392-46-7
Azinphos-ethyl	Guthion, Gusathion A	R, V	2642-71-9
Azinphos-methyl	Cotnion-methyl, Gusathion M, Guthion	R	86-50-0
Bendiocarb	Ficam, Garvox, Seedox, Tattoo	V	22781-23-3
BHC (benzene hexachloride)	see HCH	R	
BPMC (Fenobucarb)	Bassa, Baycarb, Osbac	R	3766-81-2
Bromophos	Nexion	V	2104-96-3
Bromophos-ethyl	Nexagan	V	4824-78-6
Bti H-14	Bactimos, Tecknar, Vectobac	L	
Bufencarb	Bux	R	8065-36-9
Carbaryl	Denapon, NAX, Sevin	R, L, V	63-25-2
Carbofuran	Curaterr, Furadan, Yaltox	R	1563-66-2
Carbophenothion	Garrathion, Trithion	R	786-19-6
Carbosulfan	Advantage, Marshal	L	55285-14-8
Cartap	Cadan, Padan, Sanvex, Thiobel, Vegetox	R	15263-53-3
Chlordimeform	Fundal, Galecron, Spanone	R	6164-98-3
Chlorfenvinphos	Apachlor, Birlane, Sapecron	R	470-90-6
Chlorphoxim	Baythion C	L, V	14816-20-7
Chlorpyrifos	Dursban, Lorsban	R, V, L	2921-88-2
Cyanofenphos	Surecide	R	13067-93-1
DDT	numerous trade names	L, R, V	50-29-3
Deltamethrin	Decis, K-Othrine	L, R	52918-63-5
Demeton-S-methyl	Demetox,Metasystox, Metasystox-55	R	919-86-8
Diazinon	Basudin, Diazitol, Knox-out, Neocidal,	R, V	333-41-5
Dichlorvos	Dedevap, Nogos, Nuvan, Vapona	R, V	62-73-7
Dicrotophos	Bidrin, Carbicron, Diapadrin, Ektafos	R	141-66-2
Dieldrin	Dieldrex, Dieldrite, Octalox	V	60-57-1
Diflubenzuron	Dimilin	L	35367-38-5
Dimethoate	Cygon, Perfekthion, Rogor, Roxion,	R, V	60-51-5
Dioxacarb	Elocron, Famid	V	6988-21-2
Disulfoton	Ektadin TD, Disyston, Solvirex	R	298-04-4
Endosulfan	Thiodan	R, P	115-29-7
EPN	EPN	R	2104-64-5
Ethoprophos	Mocap, Prophos	R	13194-48-4
Ethyl DDD	Perthane	R	72-56-0
Fenitrothion	Accothion, Folithion, Sumithion	R, L, V	122-14-5
Fensulfothion	Dasanit, Terracur-P	R	115-90-2
Fenthion	Baycid, Baytex, Entex, Lebaycid, Mercaptophos, Tiguvon	R, L, V	55-38-9
Formothion	Aflix, Anthio	R	2540-82-1
HCH (Gamma-HCH)	Gammexane and others	P, R, V	608-73-1 (3) 58-89-9 (4)
Heptachlor		R	76-44-8

Chemical name

O,S-dimethyl acetylphosphoramidothioate
4-(di-2-propenylamino)-3,5-dimethylphenyl methylcarbamate
O,O-diethyl S-[(4-oxo-1,2,3-benzotriazin-3(4H)-yl)methyl] phosphorodithioate
O,O-dimethyl S-[(4-oxo-1,2,3-benzotriazin-3(4H)-yl)-methyl] phosphorodithioate
2,2-dimethyl-1,3-benzodioxol-4-yl methylcarbamate
see HCH (12-45% gamma isomer)
2-(1-methylpropyl)phenyl methylcarbamate
O-(4-bromo-2,5-dichlorophenyl) O,O-dimethyl phosphorothioate
O-(4-bromo-2,5-dichlorophenyl) O,O-diethyl phosphorothioate
Bacillus thuringiensis var. israelensis. Microbial insecticide
3-(1-methylbutyl)phenyl methylcarbamate and 3-(1-ethylpropyl)phenyl methylcarbamate
1-naphthalenyl methylcarbamate
2,3-dihydro-2,2-dimethyl-7-benzofuranyl methylcarbamate
S-[[(4-chlorophenyl)thio]-methyl] O,O-diethyl phosphorodithioate
2,3-dihydro-2,2-dimethyl-7-benzofuranyl [(dibutylamino)thio]methylcarbamate
S,S'-[2-(dimethylamino)-1,3-propanediyl] dicarbamothioate
N'-(4-chloro-2-methylphenyl)-N,N-dimethylmethanimidamide
2-chloro-1-(2,4-dichlorophenyl)ethenyl diethyl phosphate
7-(2-chlorophenyl)-4-ethoxy-3,5-dioxa-6-aza-4-phosphaoct-6-ene-8-nitrile 4-sulfide
O,O-diethyl O-(3,5,6-trichloro-2-pyridinyl) phosphorothioate
O-4-cyanophenyl O-ethyl phenylphosphonothioate
1,1'-(2,2,2-trichloroethylidene)bis[4-chlorobenzene]
[1R-[1α(S*),3α]]-cyano(3-phenoxyphenyl)methyl 3-(2,2-dibromoethenyl)-2,2-dimethylcyclopropanecarboxylate
S-[2-(ethylthio)ethyl] O,O-dimethyl phosphorothioate
O,O-diethyl O-[6-methyl-2-(1-methylethyl)-4-pyrimidinyl] phosphorothioate
2,2-dichloroethenyl dimethyl phosphate
(E)-3-(dimethylamino)-1-methyl-3-oxo-1-propenyl dimethyl phosphate
1aα,2β,2aα,3β,6β,6aα,7β,7aα)-3,4,5,6,9,9-hexachloro-1a,2,2a,3,6,6a,7,7a-octahydro-2,7:3,6-dimethanonaphth[2,3-b]oxirene
N-[[(4-chlorophenyl)amino]carbonyl]-2,6-difluorobenzamide
O,O-dimethyl S-[2-(methylamino)-2-oxoethyl] phosphorodithioate
2-(1,3-dioxolan-2-yl)phenyl methylcarbamate
O,O-diethyl S-[2-(ethylthio)ethyl] phosphorodithioate
6,7,8,9,10,10-hexachloro-1,5,5a,6,9,9a-hexahydro-6,9-methano-2,4,3-benzodioxathiepin 3-oxide
O-ethyl O-(4-nitrophenyl) phenylphosphonothioate
O-ethyl S,S-dipropyl phosphorodithioate
1,1'-(2,2-dichloroethylidene)bis[4-ethylbenzene]
O,O-dimethyl O-(3-methyl-4-nitrophenyl) phosphorothioate
O,O-diethyl O-[4-(methylsulfinyl)phenyl] phosphorothioate
O,O-dimethyl O-[3-methyl-4-(methylthio)phenyl] phosphorothioate

S-[2-(formylmethylamino)-2-oxoethyl] O,O-dimethyl phosphorodithioate
1,2,3,4,5,6-hexachlorocyclohexane (mixed isomers)

1,4,5,6,7,8,8-heptachloro-3a,4,7,7a-tetrahydro-4,7-methano-1H-indene

APPENDIX (continued/1)

Common name	Trade names (1)	Uses (cited in text) (2)	C. A. Registry No.
Iodofenphos	Nuvanol N	L, V	18181-70-9
Isoprocarb (MIPC)	Etrofolan, Mipcin	R	2631-40-5
Isothioate	Hosdon	R	36614-38-7
Larvicidal oil	Flit MLO	L, V	
Leptophos	Abar, Phosvel	R	21609-90-5
Lindane	Gammalin-20, (see HCH)	P, R	
Malathion	Cythion and others	R, L, V	121-75-5
Mephosfolan	Cytrolane	R	950-10-7
Methamidophos	Monitor, Tamaron	R	10265-92-6
Methomyl	Lannate, Nudrin	R	16752-77-5
Methoprene	Altosid, Diacon, Minex, Precor	L	40596-69-8
Methoxychlor	Marlate	L, V	72-43-5
Methyl-parathion	Metacide, Folidol-M	L	298-00-00
MIPC	see Isoprocarb		
Monocrotophos	Azodrin, Crotos, Nuvacron	R	6923-22-4
MPMC (Xylylcarb)	Meobal	R	2425-10-7
MTMC (Metolcarb)	Metacrate, Tsumacide	R	1129-41-5
Naled	Dibrom, Hibrom	R, V	300-76-5
Oxydemeton-methyl	Metasystox-R	R	301-12-2
Parathion	Fosferno, Niran, Thiophos	L, R	56-38-2
Parathion-methyl	see Methyl-parathion		
Paris green		L	12002-03-8
Permethrin	Ambush, Dragnet, Kafil, Perthrine, Pounce, Pramex	L	52645-53-1
Phenthoate	Cidial, Elsan, Papthion	R, V	2597-03-7
Phorate	Thimet	R	298-02-2
Phosmet	Imidan, Prolate	R	732-11-6
Phosphamidon	Dimecron	R	13171-21-6
Phoxim	Baythion, Volaton	R, L	14816-18-3
Pirimiphos-methyl	Actellic, Blex, Silo San	L, V	29232-93-7
Propaphos	Kayaphos	R	7292-16-2
Propoxur	Arprocarb, Baygon, Suncide, Unden	R, V	114-26-1
Pyrethroids	see Permethrin and Deltamethrin	V	
Pyrethrum (pyrethrins)		V	8003-34-7
Pyridaphenthion	Ofanak	R	
Salithion (Dioxabenzofos)	Salithion	R	3811-49-2
SD 8280	Rangado	R	
Temephos	Abate and others	L, V	3383-96-8
Triazophos	Hostathion	R	24017-47-8
Trichlorfon	Dipterex, Dylox, Neguvon, Tugon	R, V	52-68-6
XMC	Cosban, Macbal	R	2655-14-3

Chemical name

O-(2,5-dichloro-4-iodophenyl) O,O-dimethyl phosphorothioate
2-(1-methylethyl)phenyl methylcarbamate
O,O-dimethyl S-[2-[(1-methylethyl)thio]ethyl] phosphorodithioate
Petroleum hydrocarbon mixtures
O-(4-bromo-2,5-dichlorophenyl) O-methyl phenylphosphonothioate
HCH, gamma isomer of not less than 99%
diethyl [(dimethoxyphosphinothioyl)thio]butanedioate
diethyl (4-methyl-1,3-dithiolan-2-ylidene)phosphoramidate
O,S-dimethyl phosphoramidothioate
methyl N-[[(methylamino)carbonyl]oxy]ethanimidothioate
(E,E)-1-methylethyl 11-methoxy-3,7,11-trimethyl-2,4-dodecadienoate
1,1'-(2,2,2-trichloroethylidene)bis[4-methoxybenzene]
O,O-dimethyl O-(4-nitrophenyl) phosphorothioate

(E)-dimethyl 1-methyl-3-(methylamino)-3-oxo-1-propenyl phosphate
3,4-dimethylphenyl methylcarbamate
3-methylphenyl methylcarbamate
1,2-dibromo-2,2-dichloroethyl dimethyl phosphate
S-[2-(ethylsulfinyl)ethyl] O,O-dimethyl phosphorothioate
O,O-diethyl O-(4-nitrophenyl) phosphorothioate

bis(acetato)(hexametaarsenitotetracopper)
(3-phenoxyphenyl)methyl 3-(2,2-dichloroethenyl)-2,2-dimethylcyclopropanecarboxylate

ethyl α-[(dimethoxyphosphinothioyl)thio]benzeneacetate
O,O-diethyl S-[(ethylthio)methyl] phosphorodithioate
S-[(1,3-dihydro-1,3-dioxo-2H-isoindol-2-yl)methyl] O,O-dimethyl phosphorodithioate
2-chloro-3-(diethylamino)-1-methyl-3-oxo-1-propenyl dimethyl phosphate
4-ethoxy-7-phenyl-3,5-dioxa-6-aza-4-phosphaoct-3-ene-8-nitrile 4-sulfide
O-[2-(diethylamino)-6-methyl-4-pyrimidinyl] O,O-dimethyl phosphorothioate
4-(methylthio)phenyl dipropyl phosphate
2-(1-methylethoxy)phenyl methylcarbamate

numerous

2-methoxy-4H-1,3,2-benzodioxaphosphorin 2-sulfide
2-chloro-1-(2,4-dichlorophenyl) vinyl dimethyl phosphate (5)
O,O'-(thiodi-4,1-phenylene) bis(O,O-dimethyl phosphorothioate)
O,O-diethyl O-(1-phenyl-1H-1,2,4-triazol-3-yl) phosphorothioate
dimethyl (2,2,2-trichloro-1-hydroxyethyl)phosphonate
3,5-dimethylphenyl methylcarbamate

APPENDIX (continued/2)

Common name	Trade names (1)	Uses (cited in text) (2)	C. A. Registry No.
Herbicides			
Amitrole	Weedazol and others	Mq, W	61-82-5
Benthiocarb	see Thiobencarb		
Butachlor	Machete	R, W	23184-66-9
Copper sulphate		A	7758-99-8
2,4-D	several	R, Mq, W	94-75-7
Dalapon	Dowpon, Gramevin, Radapon	R, Mq, W	75-99-0
Diquat	Aquacide, Reglone and others	Mq	2764-72-9
Glyphosate	Roundup, Polado	R	1071-83-6
MCPA	Agroxone and others	R, Mq	94-74-6
Molinate	Ordram	R	2212-67-1
Nitrofen	Tok, Tokkorn	R, W	1836-75-5
Paraquat	Gramoxone and others	R, W	4685-14-7
Simazine	Aquazine, Gesatop and others	A	122-34-9
Thiobencarb	Bolero, Saturn	R	28249-77-6
Trifluralin	Elancolan, Treflan		1582-09-8
Molluscicides			
Nicotinanilide		M	
Niclosamide	Bayluscide, Mollutox	M, LAM	50-65-7
Trifenmorph	Frescon	M	1420-06-0
Piscicides			
Antimycin	Antimycin, Fintrol	P	
Rotenone		P	83-79-7
TFM	Lamprecid	LAM	
Toxaphene (Camphechlor)	Toxaphene	P	8001-35-2

(1) Other trade names may also exist
(2) L - larvicide; LAM - lamprey control; M - molluscicide
Mq - mosquito control; P - piscicide; R - rice pests
V - vector control; W - aquatic weed control
(3) mixed isomers
(4) gamma isomer
(5) Possible name; author's specification not clear

Note: Where information is omitted please refer to the article cited

Chemical name

1H-1,2,4-triazol-3-amine

N-(butoxymethyl)-2-chloro-N-(2,6-diethylphenyl)acetamide

(2,4-dichlorophenoxy)acetic acid
2,2-dichloropropanoic acid
6,7-dihydrodipyrido[1,2-a:2',1'-c]pyrazinediium
N-(phosphonomethyl)glycine
(4-chloro-2-methylphenoxy)acetic acid
S-ethyl hexahydro-1H-azepine-1-carbothioate
2,4-dichloro-1-(4-nitrophenoxy)benzene
1,1'-dimethyl-4,4'-dipyridinium
6-chloro-N,N'-diethyl-1,3,5-triazine-2,4-diamine
S-[(4-chlorophenyl)methyl] diethylcarbamothioate
2,6-dinitro-N,N-dipropyl-4-(trifluoromethyl)benzenamine

5-chloro-N-(2-chloro-4-nitrophenyl)-2-hydroxybenzamide
4-tritylmorpholine

an antibiotic
[2R-(2α,6aα,12aα)]-1,2,12,12a-tetrahydro-8,9-dimethoxy-2-(1-methylethenyl)[1]benzopyrano[3,4-b]furo[2,3-h][1]benzopyran-6(6aH)-one
3-trifluoromethyl-4-nitrophenol
approximately $C_{10}H_{10}Cl_8$

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