RESOLVING THE DDT DILEMMA:

Protecting Biodiversity

and Human Health

WWF

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Acknowledgments

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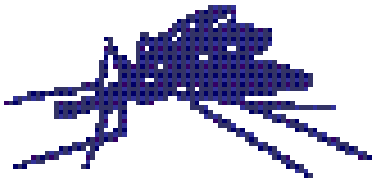
PART A

OVERVIEW



1. Introduction

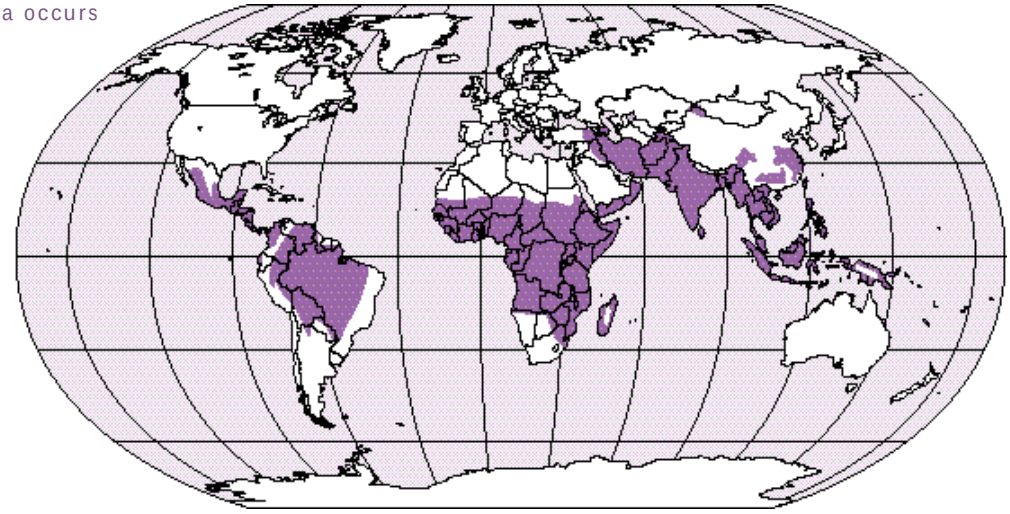
For decades, DDT has played a major role in global efforts to combat malaria and other tropical diseases. Following its initial introduction, DDT was employed with striking early success against mosquitoes and other insects ("disease vectors") transmitting diseases such as malaria, sleeping sickness, river blindness, and typhus. In 1955, the World Health Assembly, the governing body of the World Health Organization (WHO), launched a global malaria eradication initiative relying on DDT. The program eradicated or dramatically reduced malaria in 37 countries, saving millions of lives. The goal of eradicating malaria globally proved elusive, however, and malaria control subsequently replaced eradication as the goal of most national programs.

Malaria continues to be a global menace. Currently, around 2.5 billion people in over 90 countries are at risk of contracting the disease. It is one of the leading causes of illness and death in the developing world. Malaria causes or contributes up to 3 million deaths and up to 500 million clinical cases every year. Most deaths occur in sub-Saharan Africa. In Africa, malaria is among the most important causes of death and illness among children and pregnant women.[1] Children are dying at a rate of approximately 4 per minute or 5,000 per day. More than half the deaths are of children less than five years old.[2]

The resurgence of malaria stems from worsening drug and insecticide resistance; wars, natural disasters and human migrations that interrupt control operations; local climate changes; and heightened risk associated with the economic exploitation of remote areas for mining, forestry, or irrigated agriculture. Control programs have also languished as a result of international donors' diminished interest in malaria and cuts required in national operating budgets as a result of international lenders' efforts to address structural and debt problems in the economies of developing nations. Flawed decentralization strategies have also hampered the effectiveness of control programs in various countries.[3]

DDT is mainly used for the control of disease vectors in indoor house spraying – at rates of several hundred grams per dwelling, twice a year. It is now manufactured in fewer than half a dozen countries.[4] Global production levels are uncertain, but capacity was estimated in 1995 to be 35,000 metric tonnes

Map of world where malaria occurs



Malaria is the 2nd most common disease in the developing world. Between 1.5-2.7 million people die of malaria each year; more than half of these are chil - dren under five years old.

per year.[5] DDT use has declined for a combination of reasons including growing insect resistance; documented evidence of environmental damage; concern about contamination of foodstuffs; and suspicions about hazards to human health. Because DDT is regarded as relatively inexpensive, less acutely hazardous to human health than other pesticides, and has not yet been rendered ineffective everywhere by insecticide resistance, tropical disease specialists are reluctant to part with a tool still considered to be effective when malaria remains a global problem.[6]

What has not been factored into the equations is the unacceptably high hazard DDT poses to global biodiversity and human health, especially since reasonable alternatives exist. Since the last major scientific review of DDT by the World Health Organization in the early 1990s, evidence has grown that elevated concentrations of DDE, a breakdown product of DDT, are associated with reduced lactation by human mothers.[7] Research in Mexico and elsewhere has revealed measured concentrations of DDE in humans that exceed health authorities' guidelines for acceptable exposure.[8] In addition to the widely recognized association of DDE with eggshell thinning in birds of prey, there is growing evidence linking DDT and other persistent aromatic hydrocarbons (including PCBs and dioxins) to reproductive and immunotoxic effects in wildlife.[9] For example, DDT and these other chemicals have been linked to feminization and altered sex-ratios of gull populations off the California coast and the U.S./Canadian Great Lakes.[10] These effects are the result of the chemicals' disruption of sex hormones and other chemical messenger systems in these organisms.

DDT is one of a class of chemicals labelled Persistent Organic Pollutants (POPs) that are toxic and resist degradation by light, chemical reactions, and living organisms. They dissolve much more easily in fat than in water and accumulate in the fatty tissue of all living things. They evaporate at a relatively low temperature and are prone to long-range atmospheric transport and deposition and thus can cause adverse environmental and human health effects both near and far from their source.[11]

Recognizing the worldwide nature of these hazards, under the auspices of the United Nations Environment Programme (UNEP), the nations of the world are negotiating an international conven-

tion to phase out DDT and 11 other targeted POPs, and to establish mechanisms for targeting additional POPs for action. Most of the targeted POPs are pesticides. DDT is perhaps the most difficult of the listed pesticides to tackle because its principal use is in protecting public health by combating insect-borne diseases. National governments are understandably reluctant to sacrifice the use of DDT to reduce the documented and suspected hazards associated with its use.

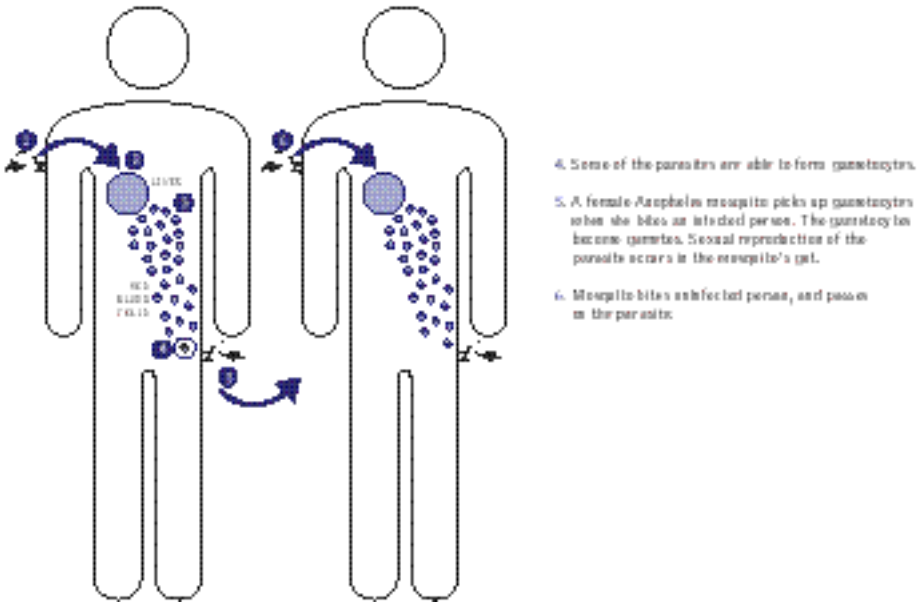
But DDT can and should be phased out – by no later than 2007. The target date coincides with a commitment made by Mexico, one of the few remaining producers of DDT in the world, to phase out its own DDT use. WWF's review of regional, national, and community-level programs targeting malaria, sleeping sickness, and river blindness indicates that a number of governments have successfully moved away from reliance on DDT for disease control, bringing disease incidence down at an affordable cost and with collateral benefits for people and biodiversity, locally and afar.

This target date for a phase out of DDT can provide an impetus for a more disciplined, coherent, and consistent effort to eliminate reliance on DDT, and to reduce overall reliance on chemical pesticides within the larger framework of Integrated Vector Management (IVM). Integrated Vector Management recognizes that many tools exist for reducing threats from insect vectors, and that vector management strategies should integrate an optimal combination of these tools rather than placing undue reliance on any single one. These tools include, for example, environmental management

Why Indoor House Spraying?

Mosquitoes tend to seek resting sites in homes before or after they feed on the human inhabitants. Understanding this behaviour, the rationale behind spraying indoor walls and other favoured resting places (e.g.; under chairs and tables) with insecticides is to kill the mosquitoes as they come into contact with the insecticide through their feet. In addition, some insecticides irritate mosquitoes and cause them to leave houses. In both these cases, the cycle of malaria transmission is broken. In the first, the mosquito does not have the chance to infect another person. In the second, the mosquito does not have the opportunity to ingest infected blood.

Cycle
transm



1. Malarial parasites mature into sporozoites in the salivary glands of a mosquito and enter a human when the mosquito bites.
2. Sporozoites invade liver cells and reproduce asexually many times, forming large numbers of merozoites.
3. The infected liver cells burst, releasing merozoites. Merozoites invade red blood cells and continue to reproduce asexually. Each red blood cell produces an average of 16 to 20 merozoites. Occasionally 32 merozoites are seen. This is because the red blood cell was originally infected with two parasites. Infected red blood cells rupture and release the parasites and the toxins that cause fever and chills.
4. Some of the parasites are able to form gametocytes.
5. A female Anopheles mosquito picks up gametocytes when she bites an infected person. The gametocytes become gametes. Sexual reproduction of the parasite occurs in the mosquito's gut.
6. Mosquito bites uninfected person, and passes on the parasite.

techniques (e.g., eliminating standing waters which harbour vector larvae), biological control (e.g., distributing fish or other predators that eat mosquito larvae, or applying natural bacterial pathogens to mosquito breeding sites), and applying insecticides (DDT or other chemicals). This enterprise can draw on the lessons learned from the successful efforts chronicled in this report and perhaps can benefit from exploratory scientific work – from vaccine development to genetic engineering – currently being pursued in laboratories around the globe.

As illustrated more fully in Section D, IVM can draw on a spectrum of vector control techniques. At one end of the spectrum are programs that rely heavily, although not exclusively, on pesticides. At the opposite end, programs rely minimally or not at all on pesticides and, when pesticides are used, selection favours ones that pose the least hazard to human health and biodiversity. Whenever pesticides of any sort are used, the frequency and volume of application should be tailored to local circumstances, based on careful analysis of disease pressures. People applying them should follow procedures that minimize hazards to themselves, others, the environment in general and particularly protected areas and sensitive species.

Integrated Vector Management is the public health analogy to Integrated Pest Management (IPM) in agriculture. IPM represents a spectrum of tools for preventing pollution.[12] At one end of the spectrum, farmers rely heavily on pesticides, but safely dispose of used containers. Farther along the spectrum is efficient, chemical-intensive IPM, involving greater precision in applying pesticides. Then come approaches that reduce reliance on pesticides, by incorporating crop rotations and other such strategies. Finally, at the opposite end is bio-intensive (biologically-based) IPM. Bio-intensive IPM places primary reliance on biological controls (e.g., enhancing beneficial organisms) and relies on chemical pesticides minimally or not at all. Scouting for the presence, or absence, of pests is an integral aspect of IPM.

IVM itself is nested within Integrated Disease Management (IDM), which encompasses a full range of public health measures, including, for example, aggressive case detection and treatment, public education, and vaccine deployment. Global initiatives to reduce reliance on DDT should mobilize financial and technical resources to promote IVM strategies that do not use DDT, reduce reliance on chemicals overall, and employ the full range of IDM techniques.

2. Organizing to Control Malaria

Many diseases are carried from one person or animal to another by some third organism, which is often termed the *vector* of the disease. Examples of disease vectors are the mosquitoes that transmit malaria, dengue fever, and yellow fever from person to person in the tropics and the tsetse flies that spread trypanosomiasis among wildlife, livestock, and people in Africa. Malaria is widespread in the tropics, with variable characteristics and epidemiology. It can be caused by four species of protozoans in the genus *Plasmodium*, and transmitted by about 70 species in the widely-distributed mosquito genus *Anopheles*

Although there may be many dimensions to programs for the control of vector-borne diseases, including vaccines, drug treatment, and protective methods such as window screens and insect repellents, these are usually combined with measures to reduce populations of the vector organisms themselves. Early national anti-malaria campaigns were implemented through military-style operations by centralized malaria control agencies independent of other public health services and with little or no community or non-governmental organization (NGO) involvement.

International Development Research Centre (IDRC)

Various Anopheles *mosquitos can transmit the malaria-causing* Plasmodium *parasite.*

The eradication strategy centred on drug treatment and spraying house interiors with DDT every six months. DDT is also sprayed inside houses in some locations to control sandflies that carry leishmaniases, fleas that spread plague, and in Russia, for combating tick-borne encephalitis. The eradication effort eliminated malaria in some countries but global eradication proved unattainable due to the lack of resources and community support and increasing insecticide and drug resistance.

This was recognized by the World Health Assembly in 1969 and after 1978, malaria control replaced eradication as the goal of most national programs. In 1978, the World Health Assembly approved the decentralization of responsibility for malaria control to local primary health care services.[13] Under this scenario, specialized malaria control services support community-based activities: local health officers detect and treat malaria cases and community members undertake vector control activities. The decentralization trend is continuing but implementation has been gradual and is still incomplete.

Decentralization and community participation are embodied in the current WHO Global Strategy for Malaria Control, which assigns a high priority to improved case detection and treatment. Especially given the paucity of resources in many countries for preventing malaria infection, disease surveillance and good clinical management is the foundation of malaria control through the general health services. It is also a basic right of affected populations. The strategy de-emphasizes interior house spraying in favour of more selective, sustainable, locally-adapted preventive measures. However, many national programs are still occupied largely with tasks inherited from eradication programs, including house spraying, which remains the preventive intervention of choice in some situations.[14] Most countries, however, are now using insecticides other than DDT for house spraying, particularly synthetic pyrethroids.[15] In addition, synthetic pyrethroids are the only chemicals currently used for impregnating bednets.[16]

The current decentralization of malaria control to local health care systems entails considerable political, organizational, administrative, and training challenges.[17] Decentralization too often adds to local responsibilities without transferring the funds needed to cover additional local expenses. The result is that community-level health services are incapable of timely and effective malaria control interventions, and case numbers surge.[18] Certain observers blame the malaria resurgence in some South American countries on decreasing DDT use.[19] That may produce the mistaken impression that there are no effective alternative chemicals for house spraying. The decrease in DDT use in South America was produced by a decrease in anti-malaria house spraying operations overall, which in some cases contributed to increased malaria transmission. This reflects the fact that large-scale house spraying is unsustainable in most developing countries, and there has not been enough political and financial support for the local adaptation and deployment of cost-effective alternative strategies.

Since DDT and its metabolites are so persistent and are transported thousands of kilometres in water and the atmosphere, it is difficult to differentiate the residues of DDT applied by public health programs from those resulting from agricultural applications. Although far more DDT has been used in agriculture than in public health applications,[22] the continuing public health use of DDT adds to existing levels of DDT residues in people and the environment. Where house spraying is common, householder and applicator body burdens of DDT residues are particularly high, as are levels in the local outdoor environment.[23]

Although DDT is supposed to be tightly controlled by Ministries of Health, it is often illegally diverted to agriculture, directly contaminating food. This has been reported or is suspected in many countries, including Mexico, Belize, Ecuador, India, Bangladesh, Tanzania, Kenya, and Madagascar.[24] The prohibition of DDT for agricultural use is virtually universal, and the agribusiness sector in some developing countries is pressing for a complete phase out because DDT residues are still causing shipments of agricultural commodities to be rejected by importing countries.[25]

Global DDT Production

Estimates of the world's current annual DDT production vary, but cumulative production is thought to be 30,000 tonnes per year. Russia, Mexico, India, and China still produce DDT for export and for domestic use in public health programs. Some other countries, such as South Korea and former Soviet Union states, may produce and export DDT as well.[26]

3. The Role of the World Health Organization

National health authorities determine the nature of their malaria control efforts, including whether or not DDT is to be used, based on specific national circumstances, priorities, and political considerations. However, they do receive and rely on guidance from the WHO and they have input to it. The Ministers of Health of member states make up the World Health Assembly, the sovereign body of the WHO. The WHO's Expert Committees collect and analyze information and the WHO supports and participates in the development of new methods and strategies for disease control, issuing recommendations and technical guidelines.[27]

For instance, the WHO Pesticide Evaluation Scheme (WHOPES), a government, pesticide industry, academic, and international agency program, promotes development and evaluation of new pesticide products and formulations for use in public health[28] WHOPES coordinates activities and technical support in WHO member states, with operational costs at the country level covered by the pesticide industry through bilateral agreements.[29] In addition, the WHO's Division of Control of Tropical Diseases has recently established a "Global Collaboration for Development of Pesticides," in which it is planning to bring together all actors in the field of pesticide development and use.[30]

The World Health Organization and DDT

The World Health Organization (WHO) is a primary source of expertise and guidance for national public health programs directed at malaria and other tropical diseases. While still endorsing the use of DDT for the protection of public health, the WHO is now more receptive to alternatives to DDT than it once was.

In 1971, the WHO indicated that the amount of DDT used for public health purposes had peaked, and that the indoor spraying of DDT in routine anti-malaria operations did not pose a significant risk to humans or wildlife.

In 1984, the WHO restated its view that DDT was the insecticide of choice for dealing with malaria vectors and that there were no acute toxic health impacts on those doing the spraying.[31]

In 1991, the WHO convened an expert panel on vector resistance to look at integrated vector control. They determined that replacement of chemical by non-chemical methods could slow down the development of resistance.[32]

In 1992, governments signed a WHO-sponsored World Declaration on the Control of Malaria and endorsed a Global Strategy for Malaria Control. The global strategy recognized the need for an integrated approach that involved early diagnosis and prompt treatment; selective and sustainable preventive measures, including vector control; prevention, early detection, and containment of epidemics; and local capacity building. The strategy recognized that in certain regions, insecticide resistance was a problem and that large-scale insecticide spraying programs were ineffective. It suggested more careful planning of spray programs and consideration of insecticide-impregnated bednets.[33]

By 1993, against the backdrop of a report on high levels of DDT in breast milk and of a possible association between DDT and the occurrence of cancer, a WHO expert group re-examined DDT. They concluded that the evidence on the adverse effects of DDT exposure as a result of indoor residual spraying was insufficient. However, because new, safer insecticides such as synthetic pyrethroids were available, the experts indicated that "DDT no longer merits being considered the only insecticide of choice."[34]

The group also urged closer examination of such health issues as cancer and exposure of babies to contaminated breast milk. A background paper for the group had concluded that "it can no longer be confidently stated that DDT anti-malarial spraying is harmless to human health."[35]

The same group also considered the larger issue of integrated vector control. They commented that while household spraying "remains a valuable tool in malaria control when applied in the right circumstances," experience demonstrated that "large-scale and continued application of insecticides is not sustainable because of financial and operational constraints, and technical problems such as the development of vector resistance to insecticides."[36]

In 1997, reflecting growing interest at various international fora in phasing out POPs, the World Health Assembly adopted a resolution to reduce reliance on insecticides for control of vector-borne disease by promoting Integrated Pest Management and ensuring that DDT was used only within programs that take an integrated approach.[37]

In late 1998, an Expert Committee will develop recommendations for consideration at the January 1999 meeting of the WHO Executive Board.[38]

In sum, the WHO and its experts, to varying degrees and using various semantic formulations (Integrated Pest Management, integrated control), have slowly embraced Integrated Vector Management and reduced reliance on DDT. The challenge now is to speed this process along, making even more explicit the need to reduce reliance on DDT specifically and pesticides more generally, and establish the financial and institutional mechanisms to make this happen.

4. The DDT Dilemma

In promoting actions to reduce pollution, WWF is placing special emphasis on reducing reliance on chemical pesticides for both disease vector and agricultural pest control because of their effects on both people and wildlife. WWF has documented hazards from pesticides, analyzed national programs designed to reduce reliance on pesticides, advocated regional reduction programs, and worked collaboratively with agricultural producers to demonstrate the benefits from reduced pesticide use.[39]

In particular, WWF has played a leading role globally in highlighting the hazards to biodiversity and human health from hormone-disrupting chemicals ("endocrine disruptors").[40] These chemicals, many of which are pesticides (including DDT), block, mimic or otherwise interfere with naturally produced chemical messengers in the body which control how organisms develop and function. They are suspected of being responsible for serious developmental, immunological, behavioral, and reproductive problems. First found in wildlife populations, and also well-documented in laboratory studies, evidence is growing that such health impacts occur in humans as well. Exposure to very small amounts – in the parts per trillion range – of an endocrine-disrupting chemical at an important stage in fetal or infant development can be more harmful than heavier doses later on. Mothers exposed to these chemicals share them with their offspring both in the womb and through breast-feeding. Growing global awareness of these hazards – and the need to respond to them – is reflected in a rapidly lengthening list of new bilateral and multilateral agreements to develop screening and testing protocols, targeted research projects, and proposals to restrict and phase out suspect products and chemicals.[41]

This new evidence has yet to be considered by the WHO in its approval process for vector-control pesticides. The dilemma is that both malaria and the chemicals used to control it pose a threat to human health. The chemicals also threaten biodiversity. Clearly, there is no room for slippage in the fight against malaria. Neither is there desire to increase environmental contamination, especially as the true magnitude of the impacts on people and wildlife come to light. Fortunately, there are disease control programs that are safer both for people and for the environment that maintain or improve protection from disease at acceptable cost, eliminate DDT, and reduce insecticide dependence. These often employ IVM principles, incorporating non-chemical vector control measures without adverse conservation impacts.

In an effort to help resolve the DDT dilemma, this report:

1) examines the use of DDT, alternative vector control insecticides, and non-chemical vector control methods in public health programs;

2) investigates householder and environmental exposure to DDT resulting from anti-malaria house spraying;

3) provides current information on the non-target impacts of both DDT and alternative chemicals;

4) offers evidence that safer options are available through six profiles from various regions and;

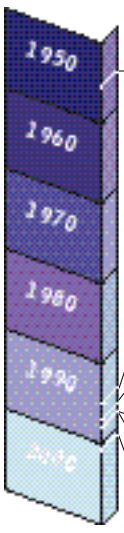
5) provides a framework and "tool kit" to move away from pesticide-dependent disease control.

The report concludes with policy and technical recommendations for an action agenda. It is directed at health and environmental specialists and policy makers in national governments, international organizations, donor agencies, and international lending institutions who are collectively responsible for the health of our planet. In particular, it is hoped that this report will be a resource for the global POPs treaty negotiations.

> "No responsible person contends that insect-borne disease should be ignored. The question that has now urgently presented itself is whether it is either wise or responsible to attack the problem by methods that are rapidly making it worse."
>
> Rachel Carson, Silent Spring, 1962.

Phase out timeline

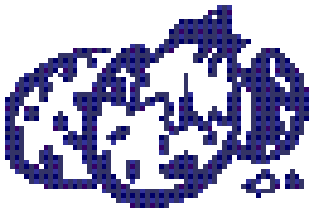
DDT has been singled out by many national governments and the United Nations Environment Programme (UNEP) for restriction or elimination because of its extraordinarily harmful pr



1955	World Health Assembly initiated malaria eradication program which relied heavily on DDT.
1995	At least 49 countries eliminated all uses of DDT because of its persistence, carcinogenicity, bioaccumulation, hazards to wildlife, and other chronic effects. In addition, DDT was severely restricted or remained unregistered in 29 other countries.[20]
June 1997	20 of 130 countries participating in the international Prior Informed Consent (PIC) procedure governing trade in hazardous chemicals still permitted the importation of DDT, mostly for use in public health campaigns.[21]
1998	Through the Convention on Long-Range Transboundary Air Pollution, 39 northern hemisphere countries agreed that DDT production should end.
June 1998	Under the United Nations Environment Programme, negotiations for a global phase out of DDT begin.
2007	Proposed phase out of DDT to be complete.

PART B

EXPOSURES AND EFFECTS



1. Introduction[1]

The WHO endorses specific pesticides from four major chemical classes for indoor spraying for malarial control: organochlorines (DDT), organophosphates, carbamates, and synthetic pyrethroids (Table 1). Each has drawbacks from a toxicological perspective. For example, organophosphates and carbamates are acutely toxic to humans, and pose a high hazard in particular to those who work with them.[2]

Synthetic pyrethroids are neither as toxic to humans as the carbamates or organophosphates nor as persistent or bioaccumulative as DDT but are highly toxic to invertebrates and can bioaccumulate. Organochlorines are associated with biomagnification up the food web and chronic effects. These effects amply illustrate the health and environmental concerns that arise from reliance on chemical pesticides. The weighty body of ecotoxicological evidence about DDT, and its continuing use despite this evidence, make it a primary and urgent focus of concern.

Table 1: Chemicals used in mosquito vector control

Key: C = carbamate; OC = Organochlorine; OP = Organophosphate; SP = Synthetic Pyrethroid (Type 1 or Type 2).[3]

Insecticide	Type	Insecticide	Type
Bendiocarb	C	Bifenthrin	SP1
Carbosulfan	C	Cyfluthrin	SP2
Propoxur	C	Cypermethrin	SP2
DDT	OC	Deltamethrin	SP2
Chlorpyrifos-methyl	OP	Etofenprox	SP1
Fenitrothion	OP	L-cyhalothrin	SP2
Malathion	OP	Permethrin	SP1
Pirimiphos-methyl	OP		

2. Persistence, Transport, and Bioaccumulation

DDT is an odourless, white crystalline chemical, available in several different forms. It has a very stable chemical structure that makes it practically insoluble in water and highly resistant to biodegradation in soils. For example, the soils of an orchard in a northwestern U.S. state still had 40 percent of the original DDT used, 20 years after the last spraying.[4]

This persistence is even more marked in water, where DDT's half-life has been estimated to be 22 years.[5] In the Philippines, despite a restricted-use status, DDT residues continue to be detected in major water bodies, as well as in fish and duck eggs. DDT can break down in sunlight and certain microbes can transform it into various degradation products but one such product, DDD, is even more persistent in soils, sediments and waters, lasting 190 years and longer.[6]

DDT's long life or persistence, once hailed as its key benefit as an insecticide, has led to its contamination of every corner of the globe and virtually every living animal and human. For example, there has been little local use of DDT in the high Arctic, but it has been found in various concentrations in all levels of the Arctic food web (See Tables 2 & 3), indicating global or hemispherical transportation by wind and water. And, despite a 25-year-old ban on use in the U.S. and Canada, concentrations in the Great Lakes are no longer declining as airborne DDT-laden particles from afar are deposited and old residues in lake bottom sediments are re-mobilized.[7]

Chemical Structure of DDT

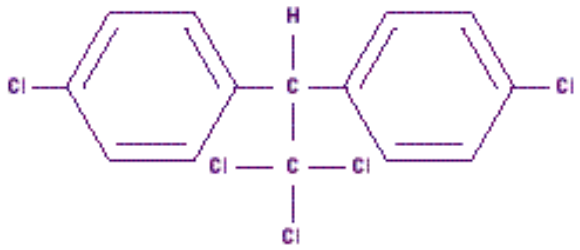


Table 2: DDT concentrations (ppb in fat) in marine biota in various locations in the high Arctic[8]

Zooplankton	8–150
Arctic Cod	15–255
Turbot	626–1251

Biomagnification

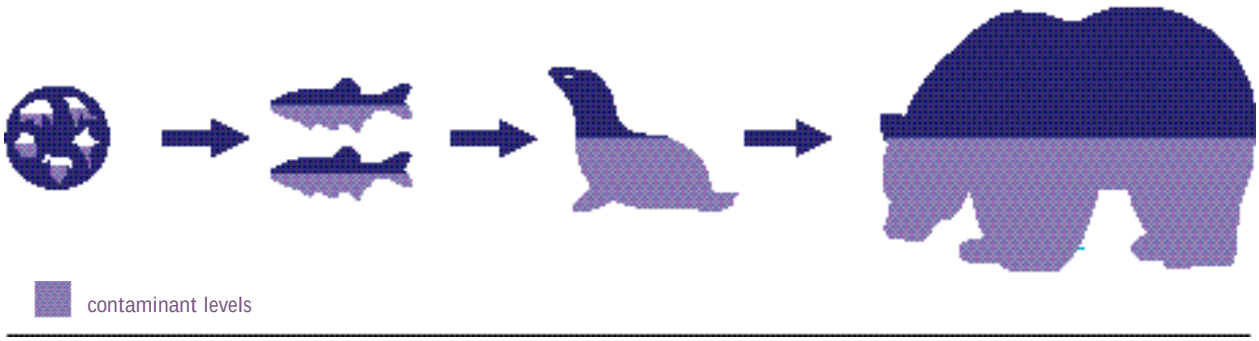


Table 3: Mean concentrations (ppb wet wt.) of total DDT in the blubber of Arctic mammals[9]

	Female	Male
Ring Seal	473	959
Harp Seal	486	NA
Beluga Whale	1940	4,974
Adult Polar Bear[10]	372	340

DDT is highly fat soluble and, even at low concentrations, can accumulate faster than an organism can rid itself of the chemical. This accumulation is magnified many hundreds of times through the food web as base-level species such as plankton and insects are eaten by fish which are in turn consumed by fish-eating species like gulls, ospreys, marine mammals and people.

Synthetic pyrethroids (permethrin, deltamethrin) are also deposited in fat cells, primarily in the central nervous and peripheral nervous systems. Although pyrethroids are not nearly as long lasting as DDT, deltamethrin has a half-life of up to two years.[11] Chronic, low-dose exposures may lead to slightly increased concentrations in the body.

Even though levels of DDT and its metabolites in the air and water are at relatively low concentrations, they cycle through the food web for decades and the ongoing accumulation in wildlife and human populations is cause for caution.

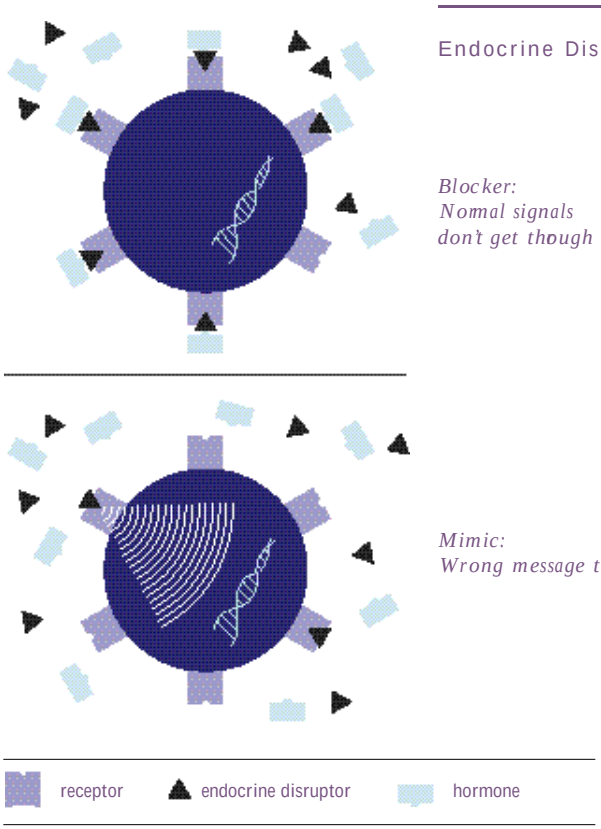
3. Health and Ecotoxicological Effects

DDT is highly toxic to fish and invertebrate species, somewhat toxic to birds, and relatively non-acutely toxic to mammals. Moderately severe poisoning through ingestion can cause cardiac and respiratory failure, brain and nerve damage and death. Other acute effects include liver damage and degeneration of the central nervous system.[12] DDT also kills sperm and lowers fertility and has been associated with premature births, absorbed fetuses and lower birth weights. DDT has also caused chronic effects on the nervous system, liver, kidney, and immune system in experimental animals. DDT is a known carcinogen in non-human mammalian species and is considered a probable human carcinogen.[13]

Pyrethroids are generally not carcinogenic, although of those used in vector control, permethrin is considered a weak tumor promoter. While pyrethroids, like DDT, are very toxic to invertebrates and other aquatic species, they are much less toxic to other species.

Recent scientific literature offers compelling evidence that there are more subtle effects than the direct acute or carcinogenic effects seen with exposure to pesticides. These subtle perturbations to neural, endocrine, and development pathways are conceptually different and can have far-reaching implications for health and survival. The following biological factors should be kept in mind:

- Events during an organism's development can result in a wide range of effects later in life.
- Even low-dose exposure has biological implications.[14,15,16]
- Interference in an organism's neural or chemical messenger systems can lead to many subtle changes in the body.
- Chemical agents may not leave "footprints in stone" – causal links are difficult to establish if an effect takes 20 years to manifest itself, or if it is transgenerational.
- All living organisms, even diverse species, share biochemical strategies – these are critical wildlife-human connections.
- Adverse effects on individuals can, cumulatively, have implications for entire populations.



The endocrine system controls development and function of the ovaries, testes, and thyroid glands. Hormones, such as estrogen, testosterone, and thyroxine, act as chemical messengers and provide the detailed instructions for neural development, sexual differentiation, the development of the immune system, sperm production, and ovulation. These operate at very low concentrations. For example, in the womb, natural hormones carry out their functions in concentrations of trillionths of a gram. Because distantly related groups like reptiles, insects, birds, mammals, and humans share an almost identical endocrine system including hormones, receptors, and similar biological responses, effects observed in one species can convey potentially important lessons regarding another.

In the past few years it has been well established that certain chemicals, like DDT, can act as hormones and have endocrine-disrupting effects, by mimicking natural hormones or blocking hormone receptors. Such chemicals disrupt an organism's developmental plan and future function, including how well an organism's immune, reproductive, and other systems perform.

In addition to DDT and its metabolites, other pesticides used in vector control such as parathion, methoxychlor, lindane, endosulfan, chlorpyrifos, malathion, diazinon, carbaryl, and some of the synthetic pyrethroids are also considered endocrine disruptors. However, since nowhere in the world current regulations governing pesticides require screening of pesticides for endocrine disruption, per se, it is not known for certain how many currently used pesticides can affect the endocrine system.

The developing offspring is the most sensitive target of endocrine disruption since much of the neural, reproductive, and immune development occurring in the womb continues into early childhood.[17] Many synthetic chemicals can cross the placental

barrier, thereby allowing the mother's body burden of chemicals to be shared with her infant.

A wide variety of endocrine-disrupting effects in many species have been observed in the natural environment and under laboratory conditions. Examples include thyroid dysfunction in birds,[18] fish,[19] and mammals;[20] growth or developmental irregularities in fish;[21,22,23] reptiles,[24,25] turtles,[26] and mammals;[27,28] behavioural abnormalities in birds;[29] demasculinization and feminization of male invertebrates,[30] fish,[31,32] birds,[33] and mammals;[34] defeminization and masculinization of female fish;[35] and compromised immune systems in birds[36] and mammals.[37]

Endocrine disruption and reproductive effects

Widespread decline in some predatory and fish-eating bird populations first came to light in the 1960s because the DDT metabolite, DDE, reduced the eggshell thickness of species such as peregrine falcons, brown pelicans, bald eagles, and osprey.[38] The thin-walled eggs were inadvertently crushed by roosting parents. As recently as 1994, peregrine falcon eggshells in the Arctic continued to be thinner than the average pre-DDT-era thickness.[39]

A more subtle but still worrisome effect was seen in the 1980s when scientists began finding evidence that DDT in concentrations as low as 2 ppm could feminize male birds by developing female reproductive organs in male embryos. Field studies of gull colonies in Lakes Michigan and Ontario found that 71 percent of male herring gulls were significantly feminized. There was also a high incidence of female-female pairings in gulls normally known for their long-lived monogamous, heterosexual pairings.[40] In birds and other species, mating habits and sexual differentiation are primarily the result of estrogen and androgen activity during fetal development. It is possible that even very low concentrations of chemicals like DDT or DDE can influence their sexual maturation. These types of effects can have serious consequences for bird populations.

Endocrine disruption and immune system effects

There is an abundance of scientific literature documenting the impacts of pesticides on immune systems and pointing to a serious health concern.[41,42] A healthy immune system involves prompt recognition and response to the presence of foreign material. If lymphocytes aren't present in sufficient numbers or their ability to replicate in response to a pathogen (i.e., virus, bacteria, or parasite) is compromised, the organism will be vulnerable to disease.

Experimental evidence in mice, rats, rabbits, and goats clearly shows that DDT and the synthetic pyrethroids cypermethrin, deltamethrin, and permethrin can lower antibody production, lymphocyte proliferation, phagocytosis rates, and white blood cell counts, any of which increases the time it takes to respond to infections. Some of these effects are transgenerational and mediated by hormones in the fetal development process. For instance, female mice exposed to DDT over six months and mated to non-exposed males had offspring with decreased production of lymphocytes.[43]

This impairment of the immune system is not just a simple matter of the level of exposure to the pesticide. Diets deficient in protein or high stress levels magnify the immune suppression caused by exposure to DDT.[44] This raises concerns for sensitive segments of the population, such as the very young, developing individuals or the elderly.

The magnitude of immune suppression from pesticides in human and wildlife populations is largely unknown.[45] However, the direct consequences of immune suppression – increased frequency of infection and cancer[46] – raise serious health concerns. Moreover, since the immune system is tightly intertwined with the endocrine and nervous system functions, indirect or subtle effects from pesticide exposures can reverberate through all – affecting the health and development of humans and wildlife.

Effects of endocrine disruption on the nervous system

Pesticides are designed to disrupt neural functioning in pests but they can also block the receptors or destroy the enzymes that play an important role in transmitting messages in the nervous systems of non-target species. If this messenger system is disrupted during fetal development or in early life, this can have far-reaching effects. For example, when mice were exposed to DDT or deltamethrin (a synthetic pyrethroid) 10 days after birth, permanent changes were seen, including increased activity and hyperactivity of the nerves, which persisted in adults four months later.[47,48] Rats exposed to low levels of deltamethrin at 9–13 days of age had lower brain and body weights, delayed neural development, and their adult brain anatomy permanently altered.[49] Adult rats exposed to deltamethrin for 15 days developed aggressive behaviour and suffered a decrease in their maze learning abilities. However, since these kinds of effects involve brain structure, direct effects to humans are difficult to assess.

Direct effects on lactation

The presence of DDT in mothers' milk has been reported since the 1950s.[50] Studies show that North American women of African origin, Inuit, and smokers generally have higher levels of DDT in their milk and other fatty tissues with levels declining over the course of lactation.[51,52,53] There is some information regarding the significance of DDT in mothers' tissues and milk for their children. For instance, there are reports that low-birth-weight babies and premature babies had higher levels of DDE in their blood compared to normal-weight and full-term babies.[54] Also, higher levels of DDT were found in the women who had the premature babies.[55]

Several studies of DDT/DDE in mothers' milk from North Carolina and northern Mexico showed that the duration of lactation was inversely related to the concentration of DDE in milk.[56,57] High levels of estrogen during pregnancy inhibit the onset of full lactation, and after birth, it is the fall in estrogen levels that, in part, allows the beginning of lactation. While not a classic endocrine-disrupting mechanism, the presence of estrogen mimics like DDT or DDE would lead to a decrease in the quantity of milk, resulting in early weaning.

Breast cancer

Concern that environmental estrogens like DDT contribute to cancer arises out of the unexplained increases in breast cancer rates over the past 25 years, coupled with the fact that breast cancer has been linked to higher levels of estrogen. Some studies[58,59] have found correlations between higher concentrations of DDT and DDE and women who had developed breast cancer, while others have not.[60] It may be that exposure *in utero* plays a role, potentially through an increase in the number of estrogen receptors during fetal development, with effects not seen until later in life. To truly establish links between DDT (and other synthetic chemicals) and the occurrence of breast cancer requires knowledge of exposure to such chemicals in the womb or during early childhood.

Alterations to breeding and parental behaviors, feminization of males, diminished fertility, developmental problems, depressed immune function, compromised neural function, and changes in social behaviors are just some of the observed effects of endocrine disruption. In some species, exposure to DDT and other POPs has resulted in population instability or crashes. The occurrence of any such changes across a population of any species, including humans, raises serious concerns. These increasingly documented hazards demand that existing reliance on pesticides for control of disease vectors be scrutinized carefully.

4. Exposure

DDT levels have declined from a global average of 12 ppm to below 7 ppm in humans and other mammals,[61] although people and wildlife in certain regions of the world have much higher concentrations. For example, women in Zimbabwe have concentrations of DDE in their breast milk which are 25 times higher than American women.[62] In many regions of the world, breast-feeding infants ingest quantities of DDT and its metabolites well in excess of the WHO's Total Daily Intake guideline of 1 ppm of fat.

By three months of age, some infants' DDT levels reach those of their mothers. But local concentrations can vary dramatically. For example, sampling of breast milk in Veracruz Mexico in 1994 and 1995 showed concentrations ranging from 0.99 to 26.9 ppm in fat. The estimated mean daily DDT intake by the infants through breast milk was 36.06 ppb/day (ranging from 5.5 to 151 ppb/day, calculated based on a mean body weight of 5 kg, a mean milk fat content of 3.5 percent and a mean milk daily intake of 0.8 L).[63]

DDT Threshold Levels

Threshold	DDT and Metabolites Concentration
Threshold (high risk)level in prey species of raptors.[64,65]	1 ppm DDE
DDE residue in peregrine falcon causing reproductive failure[66]	15-20 ppm DDE
Suspected DDE concentration affecting reproduction in heron species[67]	10 ppm DDE
Threshold for toxic effects or death of brook trout eggs[68]	1.5 ppm DDT wet weight
Threshold for lethality of salmonid eggs[69]	1–10 ppm DDT, wet weight
Suppression of reflexes in neonates[70]	>4000 ppt DDE in fat
Shortening of breast feeding duration and inhibition of lactation[71]	3000 ppt DDE in fat

Action and Advisory Levels for DDT and Metabolites

Agency	DDT and Metabolites Criteria
Great Lakes Water Quality Agreement Objectives (whole fish)	1 ppm wet weight
Health and Canada, Tolerable Daily Intake (TDI)	20 ppb/day
FAO/WHO, Tolerable Daily Intake	20 ppb/day
WHO, Drinking Water Guideline	1 ppb
WHO DDT Guideline, milk (in fat)	1 ppm
US Food and Drug Administration Action Level for fish (wet weight)	5 ppm
Health Canada, maximum allowable concentration	
Fish:	5 ppm
Eggs and fresh vegetables:	0.5 ppm
Dairy products, meat and meat by-products:	1 ppm
Drinking water	1 ppm
Michigan Department of Public Health, fish consumption advisories	5 ppm
US EPA Minimal Risk Level (MRL)	0.5 ppt/day
US EPA recommended action level	
Most fruit and vegetables:	0.1–0.5 ppm
Eggs:	0.5 ppm
Grain:	0.5 ppm
Milk:	0.05 ppm
Meat:	5 ppm

Exposures from indoor house spraying[72]

The use of DDT for indoor house spraying has generally been assumed to be a minor source of exposure to residents. This may have been the situation when DDT was in widespread and voluminous use in agriculture in the 1970s and before,

and also a prevalent contaminant in the food web. For instance, the 1993 review for WHO of anti-malaria tools considered pre-1977 data showing comparable DDT residues in the fat of residents whose houses were regularly sprayed with DDT and in the general population.[73] However, recent data indicate that many of the highest concentrations of DDT residues in humans are in areas where indoor house spraying with DDT is a common vector control measure[74] although it cannot be ascertained is whether there is unauthorized agricultural use as well. Conversely, concentrations are declining where DDT use has been discontinued.

In addition, there persists an assumption that the use of DDT indoors contributes only tiny amounts of DDT to the environment.[75] As DDT use has been deliberately and effectively scaled back in agriculture, the potential for indoor house spaying to contribute more to residents' body burden of DDT, and to environmental contamination, increases.

WWF commissioned the development of a "mass balance" model to explore this issue further. It provides an accounting of the fate of DDT and other pesticides used for indoor house spraying.[76] The model uses the concept of fugacity – the tendency of chemicals to move from one or more "components" of the environment to others – to estimate how the pesticide moves, over what period of time, and where the pesticide will end up. The key parameters used in the model are:

- the basic physical and chemical properties of the pesticide
- the physical characteristics of the room and its contents
- the affinities of the pesticide for different components of the environment, for instance with DDT, its affinity for fat versus air or water
- rates of phase transfer, e.g.: degradation, vapourization
- the behaviour of the people in the room, e.g.: inhalation rates, food consumption rates

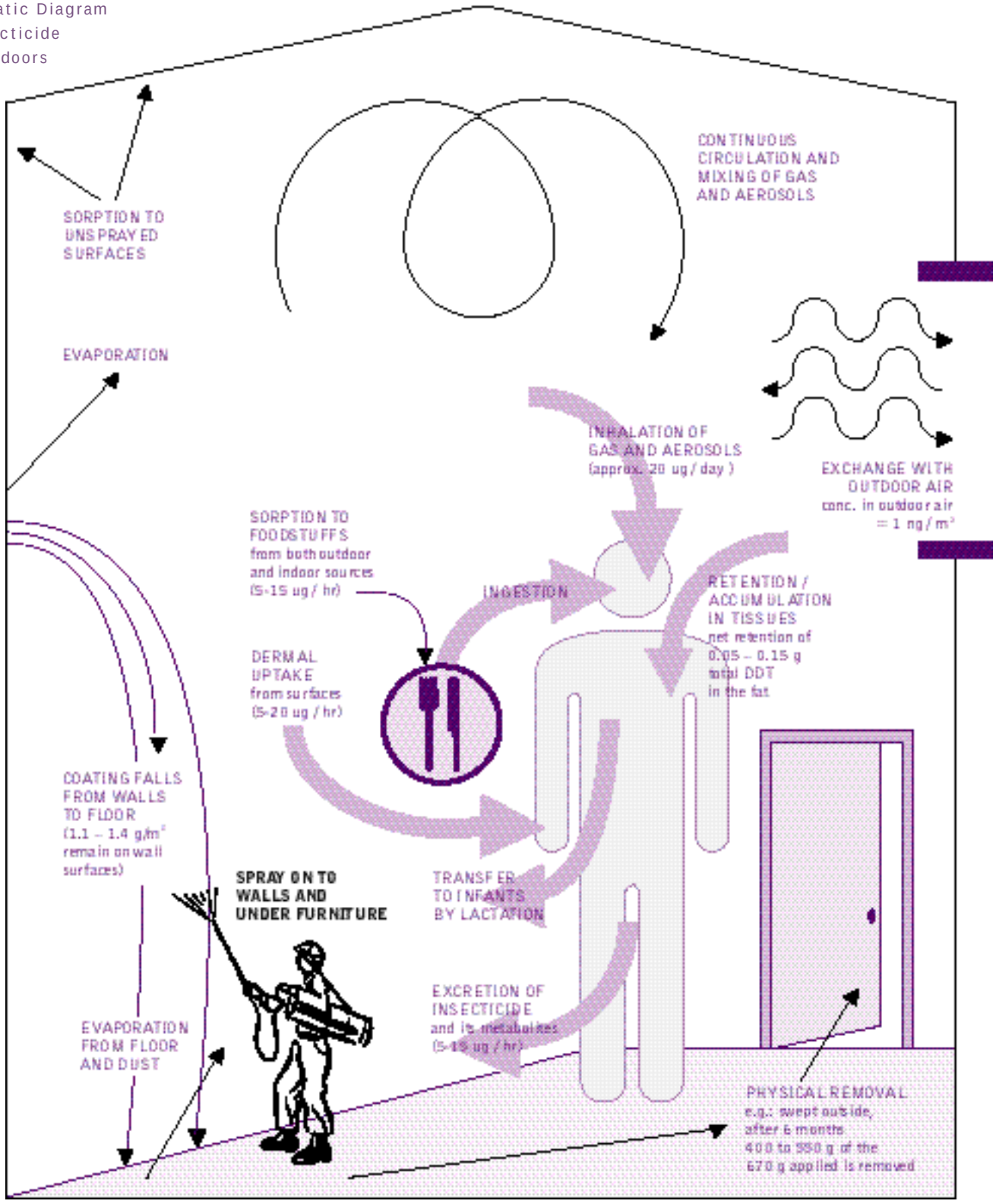
The objective of the model is to provide a quantitative picture of the fate of DDT or other pesticides which are sprayed indoors. Of particular interest are the extent of uptake by residents and extent of migration to the outdoor environment.

The mathematical model yields an estimate of the applied pesticide that remains on the walls, is transferred to air, food, and other "compartments" of the house via different routes, is transferred to the outside environment via different routes, is taken up by residents via different routes, is degraded, etc. In this case, the model only addresses a single adult male inhabitant. The very different behaviour, consumption patterns and inhalation rates of children, especially their frequent hand to mouth activity which exposes them to a great deal more contaminants via ingestion and dermal exposure, were not modelled but could conceivably yield quite different results. Neither has the potential transfer of DDT to infants via breast milk been modelled.

The mass balance model estimated the fate of DDT 180 days following a single application of 670 grams applied at the rate of 2 grams per square meter. Because of uncertainties in certain model parameters, for example the room ventilation rate, the quantities are given as range rather than as single values.

Physical removal and transfer to outdoors. Between 400 to 550 grams (60 to 82%) of the total DDT applied is physically removed from the walls and transferred outdoors. The model assumed that, because of its crystalline form, DDT would flake off the walls and onto surfaces, and would ultimately be mopped or swept outdoors. Alternatively, the DDT could be removed from the walls by washing and transferred to the outdoor environment via washwater, as surveys conducted by WWF in Mexico indicate.

Schematic Diagram
of Insecticide
Fate Indoors



Absorption into food. DDT is likely to be absorbed from air and dust into food, especially fatty foods such as butter and milk which have a high affinity for DDT. The concentrations achieved in the food may be quite large – in the range of parts per million – but the total mass of DDT in the food will be small compared to the mass in the room, i.e. less than 1 gram.

Evaporation. Direct evaporation from the wall is calculated to be minimal but does occur constantly and is based on the chemical's vapour pressure. However, since concentrations indoors are calculated to be three orders of magnitude higher than in outdoor air, it is certain that there is transfer of DDT to the outdoors in the gaseous phase.

Remaining on wall surface. Between 120 to 270 grams (18 to 40%) remain on the wall and other surfaces 5 months after the initial application. In the indoor environment, with limited light and biological activity, degradation of DDT would be especially slow. Subsequent applications will cause some buildup, but within a year or so a steady state situation will develop in which there is a fairly constant average amount of between 400–500 grams remaining on the wall surfaces, with the range being from 100–800 grams and the rate of application and the rate of loss from the room approximately equal. With a room of 360 square meters, this corresponds to 1.1 to 1.4 gram per square meter. While still almost half of the DDT applied, it is a much lower amount than the 2 g/m^2 strived for as an active dose. This would explain why standard efficacy tests to measure mosquito mortality show reduced contact insecticidal performance with time.

Human uptake. The one adult male resident is estimated to take up DDT from the indoor application in the order of 1 microgram per hour or 20 micrograms per day by inhalation. This represents a very small fraction of the DDT applied. Although concentrations in the air are calculated to be much higher than those in the outside air, inhalation is a relatively unimportant route of human exposure. On the other hand, uptake through consumption of food into which DDT has deposited or migrated and dermal contact are significant routes of exposure. The latter would be especially relevant for those who clean the walls and floors, and for infants and children who are in regular contact with contaminated surfaces.

The total uptake over a 6 month period is estimated to be in the range of 0.1 to 0.3 grams. Since approximately 50% would be excreted, there is a net retention of 0.05 to 0.15 grams total DDT in the fat. The model estimates that, with continuous exposure, i.e.: every 6 months, concentrations of DDT in the fat would increase over time in the range of 3–9 ppm of fat per year for an adult male. However, this would not continue indefinitely since, after approximately five years, the concentration would start to level off at 10 to 30 ug/g fat. This reflects a saturation point in the body and is within the range actually found in human fat in regions of the world where DDT is used or highly concentrated.

There are few experimental or monitoring data against which to validate the results of this mass balance model, although actual data on residue levels on walls and surfaces, of DDT concentrations in air, food, and residents' fat should not be difficult to obtain. The model would also benefit from refinement of the input data, including food storage and consumption patterns, cleaning behaviour, and specific information about children's food consumption and indoor behaviours.

Using the mass balance model as a screening tool indicates, overall, that much of the pesticide sprayed on walls and furniture during indoor spraying operations ends up outdoors. In addition, a small but significant amount is transferred via food to residents, which can contribute substantially to their body burden of DDT.

5. DDT's Persistence in Vector Control Programs

To regard the established effects that DDT has on wildlife as a different problem than adverse effects on human health is to create a false dichotomy. The weight of scientific evidence regarding the connection between wildlife health and human health is growing. Adverse health impacts observed in wildlife and laboratory animals from concentrations of DDT and other POPs are indicators of the potential human situation because biological processes of the endocrine, immune, nervous, and reproductive systems are common to all animals.

Moreover, many human populations depend on fish and other wildlife for a large portion of their diet. Thus, they may accumulate high levels of persistent pesticide residues, including DDT, from these sources. Inuit in northern Canada are one group whose traditional diet and mothers' milk have become dangerously contaminated.[77] The strict pesticide residue regulations on imported foods by the United States, Europe, and some Asian countries reflect health authorities' concerns about human health impacts. Where malaria control programs spray houses repeatedly, householder and applicator body burdens of DDT residues are particularly high.[78] Illegal agricultural applications of DDT also serve to compound impacts on human health.

Still, public health practitioners and policy makers, including WHO specialists and their advisors, have been reluctant to exclude the DDT weapon from their arsenal. In addition to not assigning much weight to the non-human impacts of DDT, a number of considerations underlie that stance. First, DDT is viewed as inexpensive – an important consideration when public health budgets shrink and the number of pressing health problems multiplies. It is assumed that substitute insecticides are more expensive to use and that they would have to be applied more frequently.

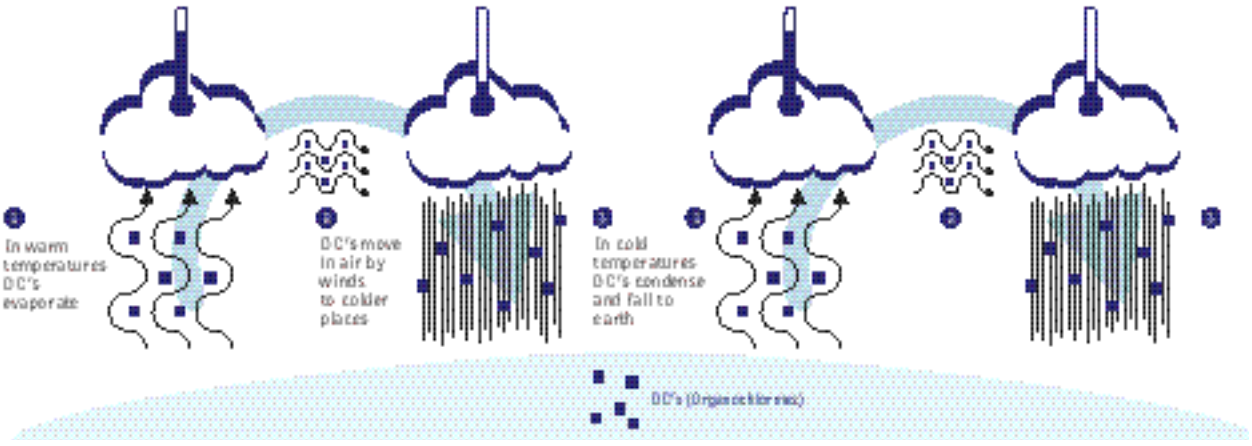
However, it is not necessary to apply synthetic pyrethroids to houses more frequently than DDT. The cost of alternative insecticides is decreasing, and their logistical and application costs may be less than for DDT. It is also reasonable to consider that pesticide manufacturers might be persuaded by donor agencies to lower the price for products used for public health, as has happened with various drugs for tropical disease treatment. And, with environmental management, biological control, and bednets lending themselves to community participation and cost-sharing, they can be cheaper than or cost about the same as DDT-based approaches. Private-sector interests and other government sectors that benefit from less-toxic disease control methods may also be willing to share costs.

Second, some alternative insecticides, particularly the organophosphates, are more acutely toxic to human beings than DDT, raising concerns among disease control specialists about the requirement for more training and expensive protective gear for the sprayors. However, the trend is toward substituting synthetic pyrethroids. These are not as toxic to humans and for them WHO is not recommending special occupational precautions.

Third, since vector resistance to insecticides is a constant threat to the effectiveness of the few products that appear safe enough for public health use, some consider it unwise to discard DDT when disease vectors in many regions are still susceptible to it. However, standard pesticide rotation and mixture techniques which do not involve DDT are available, as are less chemical-intensive options.

Fourth and last, WHO's scientific experts appear to have focused largely on what might be called traditional health endpoints – cancer and acute toxicity. There has been little, if any, attention to the new science on transgenerational impacts of DDT and other pesticides. Since WHO's last significant review of DDT in a public health context occurred in 1993, and most of the scientific literature on the impacts of these hormone-disrupting chemicals on reproductive, neural, immune, and behavioral outcomes post-dates this review, this is not surprising. However, there is now a compelling, science-based case for the re-examination of DDT and other recommended chemical alternatives.

The Grasshopper Effect



PART C

PROFILES OF ALTERNATIVE APPROACHES

1. Introduction

To investigate the feasibility of vector control methods that promote public health, prevent environmental contamination/degradation, conserve biodiversity, and are sustainable, WWF searched for successful applications for in-depth study.[1] The criteria for selection were:

- *disease control maintained or improved;*
- *use of chemical and/or non-chemical alternatives to DDT;*
- *significant reduction in insecticides used;*
- *no evidence of adverse conservation impacts; and*
- *financial feasibility.*

In addition, the selection process favoured approaches that illustrated an Integrated Vector Management (IVM) strategy and/or addressed the challenges of community involvement, scaling up pilot projects, and achieving sustainability.

Approaches relevant to Mexico's commitment to phase out DDT for malaria control, and programs that have not been previously highlighted, were given priority. The latter criterion arose because there were a considerable number of candidate profiles to choose from, including national malaria control programs in Brazil,[2] Dominican Republic,[3] and Gambia,[4] and regional and local efforts in Asia and Latin America.[5] Those chosen were drawn from Africa, Asia, and Latin America and address three major tropical vector-borne diseases.

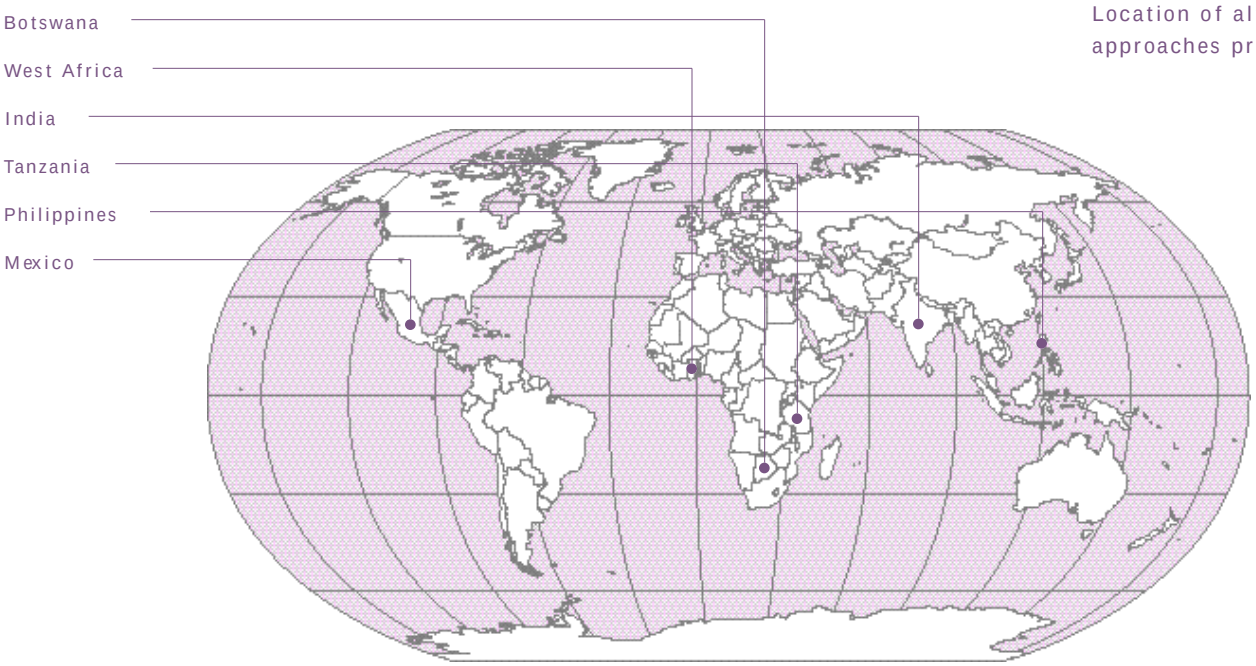
Malaria is the subject of four of the six profiles and is highlighted in the conclusions and recommendations of this report. This account, however, begins with profiles of control programs for two other

widespread vector-borne diseases, a sleeping sickness control program in Botswana, and a multi-nation river blindness control program in West Africa. These programs' innovative and environmentally aware handling of challenges similar to those still faced in malaria control, the technological commonalties, and the widely applicable ideas and principles they embody, make them potential models in many respects. In particular, both programs are notable for excellent science and a strong environmental monitoring component, which have helped them achieve impressive reductions in the amount and toxicity of the insecticides used for vector control.

The malaria profiles begin with an Indian bio-reliant IVM approach that illustrates vector control based on environmental management and biological control rather than on insecticides. A Tanzanian example addresses the deployment and impact of Insecticide Treated Nets (ITN) or bednets. The Philippine malaria control program demonstrates the incorporation of ITN into an integrated malaria control strategy similar to that implemented by many other national programs. Finally, Mexico's national program is profiled in the process of investigating options for phasing out DDT.

In each of these profiles, pesticide use was either eliminated or reduced in conjunction with dramatically lowered levels of infection and mortality. Local communities were key participants, which contributed to the success and cost-effectiveness of these alternative vector control programs. The Kheda profile, as well as many others not selected for this report, offers an example of effective vector control using non-chemical measures. All of these profiles offer strong evidence that vector-control which utilizes 50-year-old measures like DDT are no longer needed. And when the known and potential health threats of DDT are considered, continued use of it, other than under exceptional circumstances, is without basis in terms of efficacy, cost-effectiveness, or human health.

Location of alternative approaches profiled



Trypanosomiasis Control in the Okavango Delta, Botswana[6]

African trypanosomiasis, a severe disease caused by parasitic protozoans in the genus *Trypanosoma*, is called "sleeping sickness" in humans and "nagana" in cattle. In Botswana, it is a problem only in the Okavango Delta in the north of the country. The delta is one of Africa's largest and most diverse wetlands, internationally recognized as meriting protection. A multi-million-dollar tourist industry depends on controlling the disease and its vector, the tsetse fly (*Glossina morsitans centralis*). Accordingly, the Botswana government has given the program long-term political and financial support.

In 1993, after 20 years of annual ground spraying with DDT followed by the aerial application of other insecticides, the Tsetse Control Division of the Botswana Ministry of Agriculture switched to the deployment of host-odour baited cloth "targets" treated with small amounts of synthetic pyrethroid insecticide. The targets, which attract and kill tsetse, have maintained tsetse and disease control. The cost is similar to that of ground spraying with DDT, though due to high labour charges in Botswana, targets are about twice as expensive as aerial spraying.

The African tsetse control effort, including Botswana's, has benefited from excellent long-term, collaborative research by scientists in both implementing and donor countries, with the support of internationally funded regional projects. The cloth targets used in Botswana, as well as odour-baited tsetse traps used elsewhere without insecticide, represent the current state of the art. Research has also produced geographic information systems (GIS) to store, integrate, and display data, as well as a computerized data management system using global positioning via satellite to locate targets. They enable the monitoring of field operations, greatly improving target deployment

Tsetse Control Division, Botswana

Special odour-baited cloths used to trap tsetse flies can be produced and deployed by local communities.

and maintenance. In addition, the development of resistance to the synthetic pyrethroids used in targets is being anticipated with research to identify safe alternative insecticides, including insect-growth-regulating hormones and insect pathogens.

Tsetse control specialists have long demonstrated an awareness of the potential adverse environmental impacts of their health programs so they included environmental assessments and monitoring in their programs. As a result, control technologies continued to get safer and more sustainable, as well as more effective. Ground and aerial insecticide spraying led to severe acute effects on non-target animals and/or widespread contamination of wildlife with insecticide residues. In contrast, targets are relatively selective, non-polluting, and safe for workers. They reduce the hazard, persistence, and amount of insecticide used, as well as its contact with the environment and non-target species.

The Okavango Delta's cloth targets have another advantage that increases their sustainability: they lend themselves to production, deployment, and/or management by communities and the private sector. Surveys of tour operators and communities in 1996 found that large majorities of each group were willing to contribute to tsetse fly control, given appropriate compensation. Since human resources and transportation have historically been key limiting factors, these offers are potentially quite helpful. Mutually beneficial public-private partnership arrangements, involving rewards such as tax relief for tour companies and employment for community members, are under study.

Onchocerciasis Control in West Africa[7]

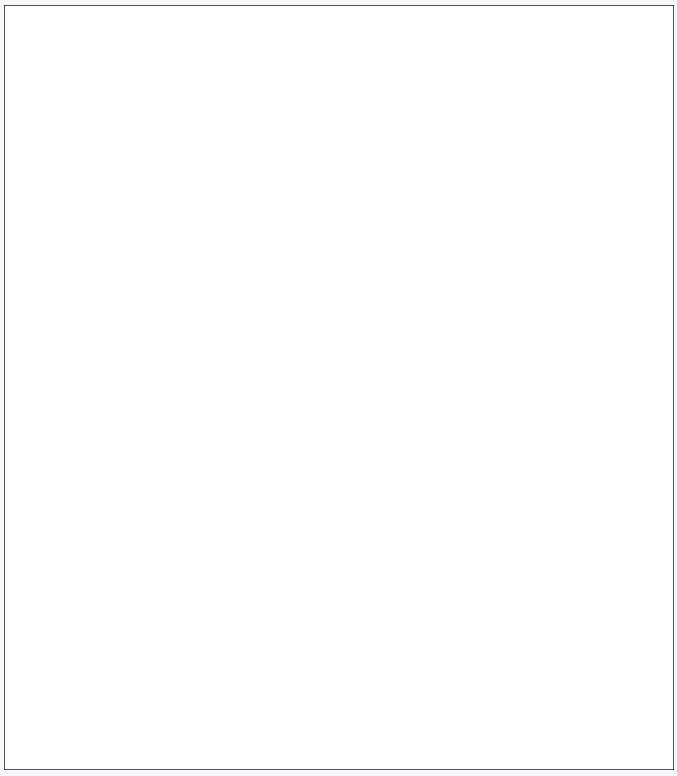
Starting in 1946, and for nearly 30 years after, DDT was applied weekly to some West African rivers to kill larvae of blackflies in the genus *Simulium*, which transmit onchocerciasis or "river blindness," a debilitating disease caused by the parasitic nematode *Onchocerca volvulus*. The Onchocerciasis Control Programme (OCP), started by a group of seven West African countries in 1974, is now achieving disease control with aerial application of much smaller amounts of alternative insecticides, combined with ivermectin, a drug treatment for infected people. The OCP, a multilateral project implemented by the WHO, was ultimately financed by a consortium of 21 donors, and expanded stepwise to cover 1.3 million square kilometres and 50,000 kilometres of rivers in 11 countries. Representatives of the WHO, the World Bank, FAO, and UNDP constitute the Committee of Sponsoring Agencies that oversees the project.

The OCP rejected DDT because of the risk of bioaccumulation and hazard to non-target species. The insecticide of choice, temephos, has a very low toxicity to

mammals and fish and a good selectivity for blackflies. However, by 1989 the blackflies had developed temephos resistance over most of the project area. Presently, resistance is managed by using temephos in rotation with other organophosphates, pyraclofos and phoxim, the carbamate carbosulfan, the synthetic pyrethroids permethrin and ethofenprox, and the biocide *Bacillus thuringiensis* (*B.t.*). The pattern of rotation is determined by roving testing teams that constantly monitor blackfly sensitivity. Resistance to temephos has regressed, and sensitivity to the other insecticides remains generally unchanged.

Applied research that cuts operational costs and maximizes results has been an integral part of the OCP. Among other things, it has helped ensure that insecticide applications are made in a way that minimizes impacts on non-target aquatic life. Since the beginning of the program, a network of 100 solar-powered water monitoring stations has transmitted information on stream depth via satellite to a ground station that uses computers to forecast water flows. This information is used to choose appropriate insecticides and dosages and to plan the most cost-effective spraying routes. Application efficiency is improved even further by computerized spray equipment in the aircraft that helps the pilot apply the larviciding specifications and nozzles that are best suited to the insecticide used, the habitat, and the amount of chemical to be discharged. This precision insecticide application prevents costly and toxic insecticide overdosing, as well as excessively low doses that can promote the development of insecticide resistance.

Specially equipped helicopters apply insecticides to West African rivers which are breeding sites for blackflies that transmit "river-blindness."



World Bank

From the beginning of the project, formally designated panels of expert advisors studied the environmental impact of the insecticides applied, approving or rejecting them for use by the program and making recommendations for environmental protection. A surveillance network was established to monitor aquatic life in the watercourses to be treated. All the insecticides chosen by the OCP degrade rapidly, have low mammalian toxicity, and do not kill fish or crustaceans at the doses and discharge rates at which they are used. *B.t.*, the most-used insecticide, has almost no non-target effects. A 1990 external review found no evident long-term effects on aquatic fauna.

That review also found that river blindness has ceased to be a public health threat in the original project zone, and vector control operations have ended in most of that area.

Over 34 million people are protected from the disease. Children born since 1975 no longer face the risk of blindness, and the disease has been halted in older persons. The program is now entering a five-year phase-out period (1998-2002), after which lasting control of the disease throughout the extended program area is expected.

A cost-benefit analysis using conservative assumptions, and with the benefit of additional agricultural output due to labor and land made available through onchocerciasis control, concluded that the OCP is a highly productive program. The economic rate of return of the OCP is about 20 percent, one of the better economic returns among World Bank projects in any sector over the years. OCP officers consider their project to be a model of global partnership where donors, international agencies, and participating countries unite to make the most of the comparative advantages of each. The success of the OCP also underlines the advantages of attacking disease problems regionally.

Ecological Malaria Control in Kheda District, Gujurat, India[8]

India's National Malaria Eradication Programme has long depended on house spraying with DDT, HCH, and malathion for vector control. The resulting widespread insecticide resistance, environmental pollution, and citizen refusal of house spraying are ongoing problems. From 1983-1989, however, the Malaria Research Centre, an autonomous research organization under the Indian Council of Medical Research, implemented an Integrated Disease Vector Control (IDVC) pilot project in Kheda District, Gujarat, which enlisted community participation for implementing an integrated, ecological malaria control strategy that eliminated insecticide use altogether.

Using larvae-eating fish such as Gambusia *is one non-chemical method of managing malaria vectors.*

Kheda District is rural and dominated by irrigated agriculture, with no conservation areas. Irrigation canals and channels are the most important breeding sites of the main malaria vector. The IDVC project protected up to 700,000 people living in Nadiad subdivision, which had the highest malaria incidence in Gujarat State. It did so by combining several non-chemical vector control methods with aggressive (weekly) village-level disease surveillance that ensured early-case detection and prompt treatment.

Health education was important for consciousness raising and eliciting community participation. Community members eliminated mosquito breeding habitats by

filling depressions, planting eucalyptus to dry out areas with a high water table, covering water surfaces with expanded polystyrene beads, and ensuring good drainage beneath water taps. Biological control with fish that eat mosquito larvae was another important component of the program: Guppies were distributed in permanent and semi-permanent water bodies, and commercially important food fish such as carp were also cultured in some ponds. Proceeds from tree nurseries and carp production paid for village improvements such as buildings, sewers, and playgrounds.

Malaria control in the IDVC project zone, as measured by the annual parasite incidence, was similar to that in the rest of Kheda district during the same period. This was achieved at a lower cost-per-person-protected than the conventional program, even excluding the value of the health and environmental protection provided by the project because no insecticides were applied during its tenure. From 1990–1996, after the project ended, an average of 7.7 metric tonnes of DDT was applied each year for malaria control in Nadiad subdivision.

As these DDT application figures indicate, malaria vector control in the project zone reverted to dependence on insecticides after the project's end in 1989. Rather than working through the existing state health and malaria control agencies, the project had been set up as a temporary, parallel structure that was neither institutionalized at the community level nor sustainable after outside funding stopped. On the one hand, the superior supervision and control afforded by this independence undoubtedly facilitated a clear demonstration of the relative merits of the alternative technologies. On the other, when project employees dispersed, they took most of the relevant experience with them. From its side, the state malaria control agency took no action to adopt or expand the effective pilot system for safer malaria control. The greatest impact of the IDVC project probably lies in its validation of alternative disease and vector control technologies that have contributed to the success of more recent integrated malaria control programs elsewhere in India.

The Bagamoyo Bednet Project, Tanzania[9]

Most countries in sub-Saharan Africa have no house spraying program and rely on drugs to control malaria. African studies show, however, that bednets treated with synthetic pyrethroid insecticide can reduce malaria incidence and child illness and death. The World Health Organization (WHO) and the Canadian International Development Research Centre (IDRC) have issued a call for operational research on how best to promote the use of insecticide-treated nets or bednets on a large scale.[10] The main challenge is making community bednet programs sustainable, given economic constraints and competing priorities at both the government and household levels.

The Bagamoyo Bednet Project was implemented from 1990–1995 in 13 villages with 22,000 people in the coastal Bagamoyo District of Tanzania. Bagamoyo is under constant, heavy malaria transmission pressure. Tanzanian health authorities, supported by specialists from the Johns Hopkins University School of Hygiene and Public Health and funding from USAID, measured the impact of permethrin-treated nets on malaria transmission and determined how to encourage community participation in implementing and sustaining the program.

Local communities were involved in all aspects of the project. Preliminary research supported the design of appropriate interventions, collected baseline data for the later evaluation of project impact, and identified community education needs. Health education was found to be essential for motivating people to make a significant investment in malaria prevention and to sleep under bednets throughout the year.

It was necessary to establish clear roles and responsibilities for participants, and mechanisms for supervision and quality control at village, local, and national levels in order to overcome five key barriers: net costs, limited awareness of the health impacts of malaria, absence of a village-level structure for net re-treatment, low willingness to pay for insecticide, and inadequate national and local government commitment to malaria control. The project gained political support by informing and involving the relevant officials and village government leaders. It was implemented step by step, with careful evaluation and improvement at each stage. As a result, the publicity, timing, location, and price of supervised net re-treatment services changed with experience. Social scientists trusted by villagers helped keep communication channels open.

Insecticide-treated bednets shield sleeping people from malaria-transmitting mosquitos.

The safety precautions for net treatment with pyrethroids are important but simple: gloves, good ventilation, and avoiding skin contact with the insecticide solution. WHO considers the dried nets to be safe, but recommends that care be taken to prevent small children from putting parts of the net in their mouths. Neither the applicators nor net users are reported to have suffered significant health problems caused by the use of nets.[11]

Pyrethroid insecticides such as permethrin have little tendency to bioaccumulate, and break down in a few years, in contrast to DDT which can take years, in both mammalian tissue and in soil. However, if periodic exposures exceed an organism's ability to metabolize these chemicals, concentrations will build up. Pyrethroids' established toxicity for fish and other aquatic organisms has important consequences for the disposal of net treat-

ment and washing liquids. In order to avoid adverse impacts on non-target species, the project recommended burial or pit latrines, in which pyrethroids degrade quickly.

Financially independent Village Mosquito Net Committees were the core components of the project. Appropriate selection of committee members, with community input and attention to traditional healers, was important for success. The committees helped plan, implement, and administer program activities and were responsible for bednet sales, distribution, and re-treatment. Sales of an initial project donation of nets and insecticide created an operating fund for each committee. Interest earned on the funds then paid for committee members' services and for further supplies of nets and insecticide. Most of the costs and management of malaria control activities were thus assumed by the beneficiaries. ITN can be inexpensive compared to house spraying with DDT, because nets are treated with a very low dose of insecticide and operations are simple and quick. Relative cost figures vary and may be influenced by the availability of inexpensive mosquito nets.[12]

Bednet coverage varied from 69 percent to 89 percent of households. Children in communities with bednets had 60 percent fewer episodes of malaria-related fever, 50 percent less malaria infections, anemia, and treatments for malaria, and grew more than unprotected children. As of 1997, Village Mosquito Net Committees were still functioning, with active revolving funds.

The Philippine National Malaria Control Program[13]

Malaria is primarily a rural problem in the Philippines, where disease incidence varies, from zero to high risk, depending on the region. The Philippine national Malaria Control Service (MCS) started using DDT for residual spraying of house interiors after World War II. Chemical vector control measures were later complemented by stream clearing and shade elimination close to settlements in order to deprive the main malaria vector of breeding sites, and stream seeding with guppies for reducing populations of mosquito larvae. These are considered relatively minor, supplementary activities.

Although malaria death rates in the Philippines have been low since the 1950s, the number of annual cases has fluctuated. Shifts in the organizational structure and administrative policies of the malaria control program, as well as changes in available financial support, have strongly influenced the success of malaria control over time. From 1959–1965, and again from 1983–1987, malaria control was decentralized operationally to the regional or provincial level and integrated fully with general health services. Periods of decentralization saw malaria control deteriorate, reflecting the low priority it received from some regional health administrators, a lack of coordination between national and regional deployment of workers, money, and goods,

as well as between regions, and inadequate re-orientation and supervision of local health personnel with malaria control responsibilities. At present, the organizational structure of the malaria control program is semi-vertical – a compromise between vertical service delivery and decentralization that is meant to provide adequate coordination, monitoring, and support of local anti-malaria activities. Devolution of responsibility for malaria control to local governments has been gradual since the decision was last made in 1992, and is still in progress.

In 1993, DDT use was banned in the Philippines for environmental reasons, no significant malaria mosquito resistance to the chemical having been documented. The Malaria Control Service replaced DDT with alternative insecticides that proved equally effective: fenitrothion, deltamethrin, cyfluthrin, lambda cyhalothrin, and bendiocarb. These chemicals were used in rotation to delay the development of insecticide resistance. In order to simplify logistics and training, however, these

E. Balon

Larvivorous Tilapia *are farmed in streams for both malaria vector control and as a source of income for community members.*

five chemicals are now being phased out in favour of a single insecticide. The synthetic pyrethroid ethofenprox was chosen because it is safer, cheaper, and as effective, and has a longer residual effect.

Also in 1993, and for similar economic and logistic reasons, the MCS reduced its dependence on residual house spraying by turning to bednets impregnated with deltamethrin or permethrin as its primary vector control measure. The MCS is working with communities to find acceptable and effective cost-sharing schemes. House spraying is further minimized through stratification of target areas according to disease transmission pressure, geographic and socio-economic factors, and population stability.

Although alternative insecticides are more expensive than DDT, bednets require less insecticide and application expense than house spraying. Average annual Philippine

expenditures for malaria control insecticides have dropped over 40 percent since DDT was banned in 1993. That decrease might have been less but for the termination in the same year of a World Bank support project, which reduced the malaria control budget from a 1991–92 average of US$5.62 million/year to a 1993–96 average of $2.04 million. Reduced resources have hampered operations and led to the allocation of scarce insecticides among provinces according to malaria case numbers.

Even in the face of that challenge, this new control strategy has reduced malaria incidence. From 1993-1996, the number of malaria cases per 100,000 population sank from 97 to 55. The program's continued success depends chiefly on community participation, including that of indigenous peoples in remote areas. Accordingly, the MCS is placing high priority on improving the social mobilization skills of field personnel. Community volunteer schemes have successfully compensated for personnel cutbacks in some provinces, and there appears to be scope for greater collaboration with non-governmental organizations (NGOs).

Apart from the hazards of DDT, environmental impacts of Philippine malaria vector control practices have received little attention. There are no special safety guidelines for malaria control activities in or near wildlife conservation areas. Significant harm from environmental management measures appears unlikely, but stream seeding with introduced fish is of greater concern, and deserves expert attention.

Collaborative research is presently under way between a university and a research institute, on family and local government empowerment for malaria control and on income generation for groups of anti-malaria volunteers. The project is investigating the farming of fish (*Tilapia)* in streams both for malaria mosquito control and as a new source of income for participating families. The MCS considers insufficient understanding of malaria vector ecology and distribution to be a significant technical limiting factor in the malaria control program, but these problems are not being addressed by researchers at the moment, and research capacity and resources are limited.

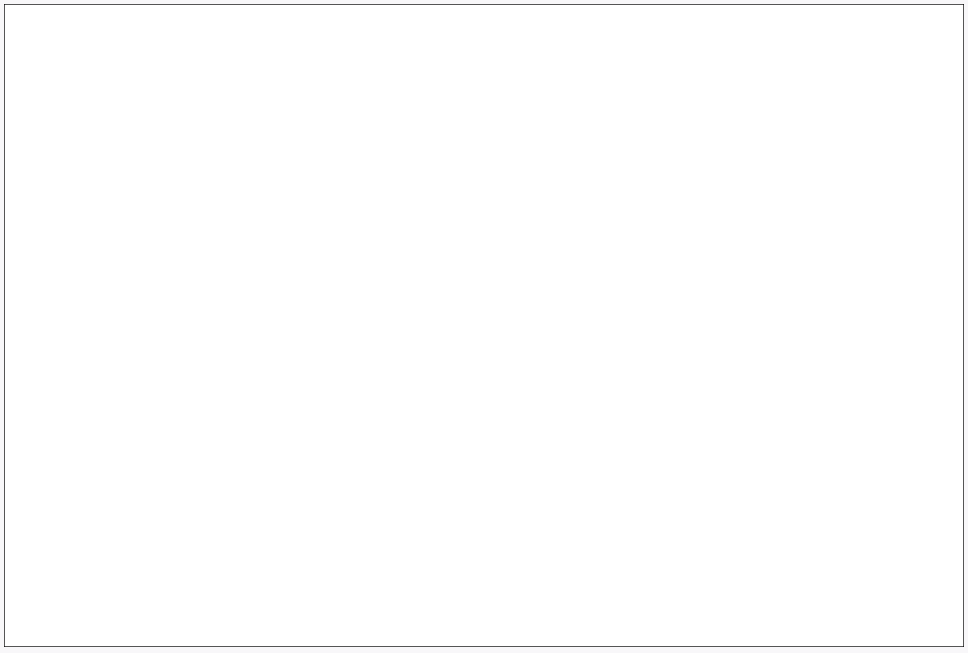
Mexico: In Transition to Malaria Control Without DDT[14]

Malaria control in Mexico is the responsibility of the Directorate of Prevention and Control of Vector-borne Diseases in the Secretariat of Health (SSA). The spraying of house interiors with DDT in malaria-endemic zones in order to kill mosquitoes that carry the disease has been the main vector control measure used since the late 1950s. A privatized corporation produces DDT for export and for malaria control, which has been the only lawful domestic use pattern for DDT since 1991. DDT spraying is just one aspect of an integrated disease control strategy that also includes case detection and treatment (largely by a network of community volunteers), epidemiological

surveillance, malathion fogging of mosquito resting and mating sites, larviciding with temephos, the mobilization of communities for the elimination of mosquito breeding sites, barriers such as bednets and screens for houses, and, at a few locations, biological control with *Gambusia* or guppies.

Community participation in the form of a strong volunteer tradition became part of Mexico's anti-malarial effort from an early stage. Critics point out, however, that these community initiatives stop short of genuine participation, i.e., giving people a role in planning, decision making, and evaluation. Rather, the community has participated as the executor of activities that are programmed, directed, and evaluated by the government, using participation as a way to reduce cost and increase coverage. NGOs are not involved in malaria control.

There have been no malaria-related deaths in Mexico since 1982. Case numbers have varied, fluctuating in response to many factors, including the effectiveness of program management. Malaria control in Mexico is entering its second round of decentralization. The first round involved decentralization of responsibility to state health agencies in 1984; however, federal funding to the states for malaria control was insufficient. Moreover, the change had been made with little preparation. State health services were reluctant to assume responsibility for the control of vector-borne diseases, and local health personnel lacked resources, incentives, and, at first, technical knowledge. Decision making and management of resources at the state level were often poor, and there was insufficient coordination between states. The number of malaria cases soared temporarily. Ultimately, only 14 of the 29 states with vector control programs integrated malaria control into their existing health structures. Starting in 1997, the decentralization of health services, including malaria



J. Ramirez

Educating community members about malaria is an important aspect of control programs in Mexico.

control, is being completed and strengthened by extending it to all states, along with increased state control of decision making and financial resources.

In real terms, government funding for malaria control in Mexico has been shrinking slowly in recent years. Nevertheless, malaria incidence has now been confined to a relatively small number of stubborn "hot spots." These areas have high mosquito densities and are particularly vulnerable because of legal and illegal immigration. Central America has relatively high malaria rates and is the source of a constant cross-border influx of new cases.

Little information is available about the malaria control program's impacts on Mexican wildlife habitat and biodiversity. Neither past engineering projects for eliminating mosquito breeding habitat nor the distribution of larvivorous fish appear to have been the subject of environmental assessments. There are no special guidelines for DDT application in or near conservation areas. Bird studies indicate that certain species in some regions, especially birds of prey, carry DDT residues at levels that could interfere with reproductive success.

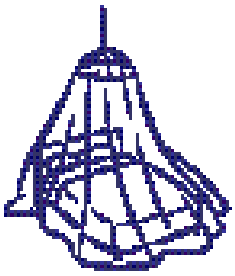
Mexico is committed to implementing the environmental protection measures of the North American Free Trade Agreement (NAFTA), which it signed in 1994 along with the United States and Canada. One of these measures is a 10-year regional DDT action plan that was approved in June 1997. That plan calls for Mexico to reduce its use of DDT for malaria control by 80 percent by the year 2001, and eliminate DDT use completely by 2007, providing that acceptably safe and effective alternatives are available.[15]

Collaboration between the SSA and malaria research programs at universities and research institutes, while historically insignificant, is being strengthened with a view to developing site-specific malaria control strategies for the remaining persistent hot spots. The principal approach, at least in the near future, will be the substitution of DDT with other insecticides with safety and low cost as the two major criteria for acceptance. Staff of the malaria control program have been collaborating formally with chemical companies to evaluate donated deltamethrin and lambda cyhalothrin for house spraying and bednet treatment. Results have been encouraging, and these experiments are being scaled up. The Secretariat of Health is also involved in a project, funded under the environmental provisions of NAFTA, that is evaluating parasitic nematodes for biological vector control. Cost-effectiveness data should be available soon for all the vector control measures being tested.

Especially because deltamethrin and lambda cyhalothrin are widely used in agriculture in Mexico, the development of malaria mosquito resistance to them is likely. Deltamethrin resistance has already been documented. A rotation of deltamethrin with the organophosphate insecticide pyrimifos-methyl for house spraying is under study for retarding resistance development.

PART D

RESOLVING THE DDT DILEMMA:
Reducing Reliance on and Use of DDT and Other Pesticides in the Context of Integrated Vector Control (IVM)



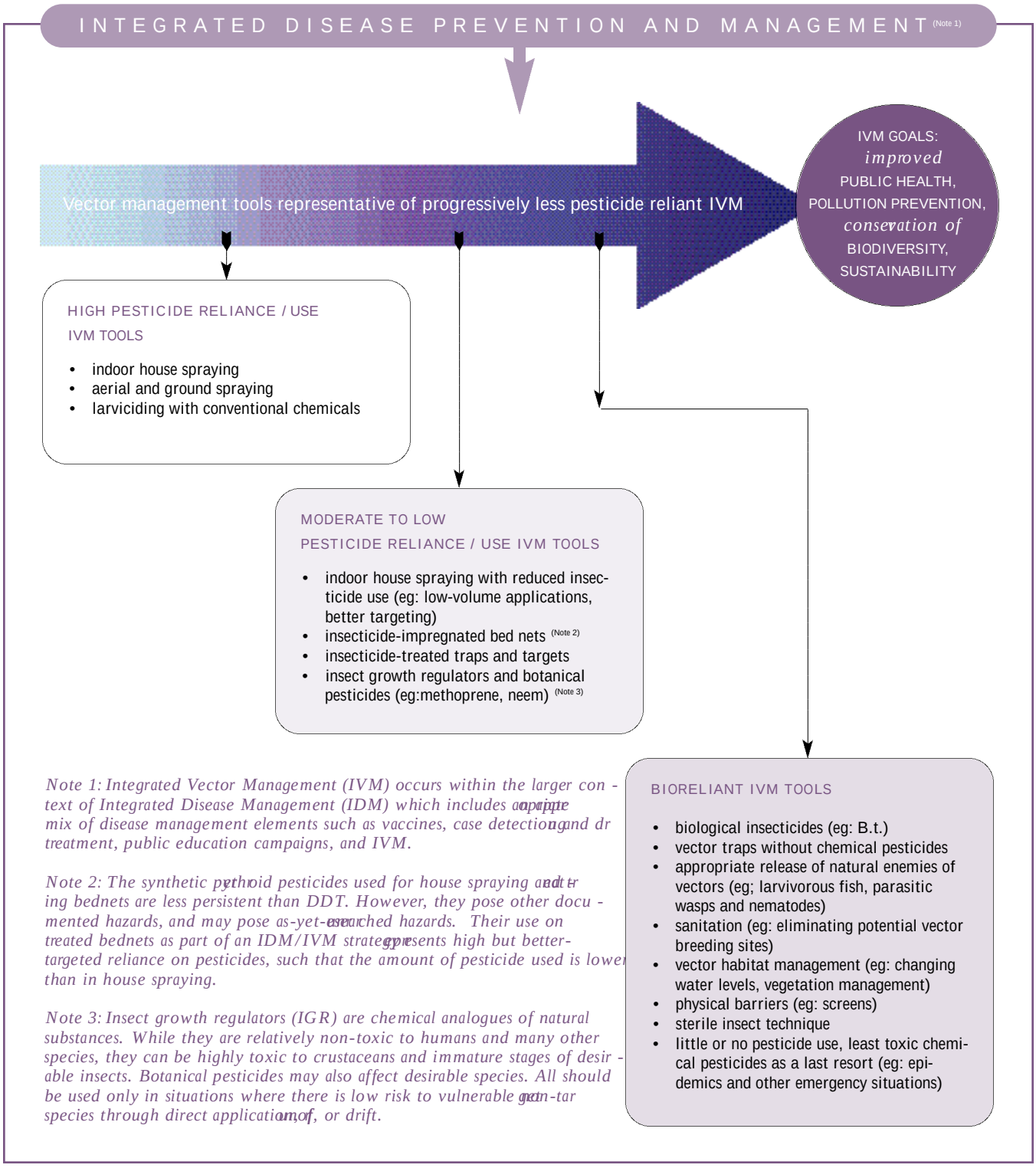
1. Introduction

The profiles featured in this report of diverse approaches taken to successfully reduce the toll from malaria and other tropical diseases illustrate the feasibility of eliminating DDT use and reducing overall reliance on pesticides. Integrated Vector Management (IVM), which involves careful planning of multi-faceted intervention strategies, is a good context for achieving these goals. Alternative pesticides, targeted pesticide use, and non-pesticide vector control methods can all be part of an effective integrated approach to reducing threats from disease vectors. IVM, complemented other disease management approaches such as vaccines, enhanced case detection, treatment, and health education programs, constitutes Integrated Disease Management (IDM).

Because of the established and suspected hazards pesticides pose to human health and biodiversity, it is prudent to implement steps to reduce use whenever and wherever possible. The first step is to ensure insecticide applications are targeted in space and time to eliminate excessive use. However, wise use of pesticides does not constitute pollution prevention oriented IVM. The next quantum step is to adopt sustainable multi-faceted intervention strategies that rely mainly on non-chemical approaches and use pesticides only as a last resort.

Improved targeting of interventions – which can both reduce cost and minimize environmental and health hazards – demands better-informed decision making. It requires strengthening existing disease surveillance activities and expanding them to include data on vectors, pesticide use, biodiversity, and wildlife habitat. It calls for exploring the usefulness of new technologies such as Geographic Information Systems (GIS) and remote sensing for data gathering integration and management. Training, technology transfer, and information transfer are essential to realizing this objective.

The Integrated Vector Management Spectrum



Note 1: Integrated Vector Management (IVM) occurs within the larger context of Integrated Disease Management (IDM) which includes appropriate mix of disease management elements such as vaccines, case detection and treatment, public education campaigns, and IVM.

Note 2: The synthetic pyrethroid pesticides used for house spraying and treating bednets are less persistent than DDT. However, they pose other documented hazards, and may pose as-yet-unresearched hazards. Their use on treated bednets as part of an IDM/IVM strategy represents high but better-targeted reliance on pesticides, such that the amount of pesticide used is lower than in house spraying.

Note 3: Insect growth regulators (IGR) are chemical analogues of natural substances. While they are relatively non-toxic to humans and many other species, they can be highly toxic to crustaceans and immature stages of desirable insects. Botanical pesticides may also affect desirable species. All should be used only in situations where there is low risk to vulnerable non-target species through direct application, runoff, or drift.

The intergrated vector management spectrum diagram illustrates the direction in which vector control methods should be moving – from high reliance on and use of pesticides toward "bio-reliant" non-chemical vector control tools. At the left-hand end of the spectrum for example, calendar-based spraying (e.g., spraying large areas at specified times of the year, without detailed knowledge of the breadth and intensity of the vector threat) represents a strategy of high reliance on pesticides. More targeted spraying, and reliance on insecticide-impregnated bednets, represents reduced use of pesticides. The most bio-reliant IVM approaches will use biological methods such as larvivorous fish, environmental management methods such as eliminating breeding areas, and screens.

The relative weight given to any form of vector control – whether highly or scarcely reliant on pesticides – as compared to disease management techniques such as aggressive case detection and drug therapy, requires a careful assessment of national and local circumstances. In addition, bio-reliant IVM is not a universal panacea. For instance, it may not be appropriate to specific conditions in particular locales. Moreover, though policy-makers should try to reduce the role of pesticides in their vector control strategies for routine situations, rapid pesticide-intensive interventions may be the most effective response to emergencies such as incipient epidemics. Nevertheless, initiatives profiled in this report clearly demonstrate that, with proper dedication, resources, and incentives, vector control programs can move successfully along the IVM spectrum toward strategies that reduce reliance on and use of chemical pesticides.

2. The IVM Tool Kit

WWF recognizes that while many vector management specialists can readily embrace large parts of this IVM spectrum, they are reticent to embrace the bio-reliant approach because they are unsure of how soon, if at all, this objective can be reached. While WWF cannot guarantee the success of a bio-reliant approach, it offers significant promise. Setting such an approach as the ultimate objective should encourage and foster movement in that direction all along the spectrum, not that dissimilar to the general direction desired by many vector management specialists interested in reducing their dependence on chemical pesticides. Furthermore, WWF believes that not setting bio-reliant IVM goals surely guarantees their non-accomplishment, and opportunities to better protect both public health and biodiversity will be missed.

Physical barriers

Physical barriers that prevent disease vectors from reaching and biting people are an important component of disease control. Examples are the use of protective clothing and mosquito nets, and improving houses by installing screens on doors and windows. The routine use of these precautions should be encouraged.

Vector habitat management

Removing or altering vector habitat or breeding sites can effectively suppress vector numbers, at least locally. The drainage and elimination of wetlands, permanently or temporarily, played a major role in the eradication of malaria in the southeastern United States by the early 1950s and in Israel/

Palestine by the 1960s, and in making much of Italy malaria-free before World War II.[1] Those successes undoubtedly came at the expense of biodiversity, and only more recently has the important role wetlands play in a healthy ecosystem been recognized and alarms sounded over their extensive disappearance. However, as initiatives in Florida, U.S., and Venezuela demonstrate, it is possible to control mosquitoes and mosquito-borne diseases while preserving and carefully managing wetlands.[2] Conservation is usually not an issue with regard to managing irrigation canals or other non-natural habitats. However, environmental management efforts in natural water bodies should be preceded by biodiversity surveys and the careful choice of measures that ensure the preservation of rare or unique habitats.

Introduction of natural enemies

Vectors can be controlled by enhancing the distribution and density of their natural parasites or pathogens, and/or predators. This is most effective at the larval stage; animals that eat the larvae of mosquitoes and other vectors are often labelled *larvivorous*. For example, Central American "mosquito fish" (*Gambusia affinis*), South American guppies (*Poecilia reticulata*), African *Tilapia*, and other larvivorous fish have been seeded into artificial and natural wetlands and bodies of water as part of disease control programs in many countries.

Some national malaria control programs, such as the one in the Philippines, have inherited the distribution of exotic larvivorous fish as a long-standing component of IVM. New initiatives, such as the production of *Tilapia* in Philippine streams and a malaria control program that produces and distributes guppies in Karnataka, India,[3] are being undertaken as well.

However, introduction of non-native species can pose a threat to biodiversity. Hardy, highly-adaptive fish can outcompete indigenous species or races, altering fish population levels permanently or even driving local fish to extinction, or endangering valuable non-target prey. For instance, *Gambusia* are suspected of reducing numbers of *Litoria aurea*, a frog recognized in Australia as "threatened," by eating its tadpoles.[4] The WHO recommends that fish distributed for vector control originate from the same area where biological control is to be effected.[5]

Ongoing biological control activities with fish or other predators or pathogens should be critically evaluated, and new ones should pass safety screening, with a view to protecting biodiversity. If consideration is being given to introducing exotic predators, parasites, or pathogens into new environments, laboratory-based host range studies must be done beforehand to confirm that they will not harm desirable species, in addition to the target vectors, or undermine local biodiversity. In general, pathogens and parasites are much more host-specific than higher organisms.

Traps and targets

Various kinds of vector traps can be deployed as relatively specific, low- or no-insecticide components of IVM strategies. For example, the tsetse fly control program in Botswana uses host odor-baited traps with a small amount of insecticide, and a variant, insecticide-treated cloth "targets," for targeting trypanosomiasis vectors effectively with a minimum amount of chemical insecticide. Other tsetse control programs deploy fly traps that contain no insecticide at all.[6] Similarly, visual, chemical, and sound clues are being investigated for attracting mosquitoes to traps that would sterilize or kill them.[7]

Sterile insect release

The sterile insect technique entails the mass release of sterilized vector individuals to control field populations by blocking their reproduction. This approach, combined with traps, targets, and/or cattle dipping appears to have eradicated tsetse flies from some regions of Africa.[8] It may be an alternative for future use in the Okavango Delta of Botswana, should insecticide-treated targets alone fail to effect long-term tsetse control.[9]

Bed nets

The strong donor effort currently behind the development and deployment of impregnated nets may result in this option becoming a dominant global malaria vector control paradigm, as house spraying with DDT was. Bednets involve the use of lower total volumes of much less persist e n t and bioaccumulative pesticides.

However, when more is known about the effects of human exposure to synthetic pyrethroid-treated bednets, they, like DDT before them, might be rejected in many areas of the world as too dangerous for general use. Substituting insecticides or repellents in bednets that are non-toxic or less toxic for people could, however, mitigate that problem. Another issue that has been raised is the possible loss of immunity to malaria in some parts of Africa as a result of the partial protection from bednets, but its significance is little understood at this time.

While bednets have been highly effective in some settings, there is a danger that malaria control programs in many regions of the world will simply, and unnecessarily, become locked into yet another narrow insecticide-dependent paradigm. An excessive focus on bednets could monopolize resources and discourage initiative needed for developing and implementing the locally appropriate IVM approaches called for under the Global Strategy for Malaria Control. The goal of moving toward safer and better-adapted vector control measures, particularly non-chemical ones, must be kept in view and should continue to receive priority.

Resistance management techniques

The development of resistance to pesticides by target pests can endanger the usefulness of vector control methods that employ insecticides. Insecticide resistance management in agriculture and public health relies on chemical rotations or mixtures. For example, the Onchocerciasis Control Programme avoided resistance development, even rolling back resistance to the larvicide temephos, with a rotation of several insecticides for which insects' detoxification mechanisms differ. A rotation of pyrethroid and organophosphate insecticides for house spraying is being tested in Mexico,[10] and application of a mixture of independently acting compounds has been proposed for avoiding resistance to impregnated bednets.[11] The availability of effective botanical and biological insecticides increases options when resistance to conventional pesticides becomes unmanageable, or when designing insecticide rotations.

Targeting and volume reduction

Better targeting and technology for insecticide application can reduce amounts required. For example, Mexican researchers are testing low-volume application, and the selective spraying of indoor surfaces to bring house spraying costs down.[12]

Substitute pesticides for indoor and outdoor applications – synthetic, botanical, biological

Insecticides of many types, including organophosphates, carbamates, synthetic pyrethroids, and biological insecticides such as B.t., may be substituted for DDT in various situations. Synthetic pyrethroids are the most commonly used substitutes for DDT in public health programs, including for house spraying to kill malaria vectors.

Pyrethroids are generally less acutely toxic to humans than, for example, organophosphates and no exceptional safety precautions, protective clothing, or frequent monitoring of people who apply them for signs of poisoning, has been officially recommended.[13] However, they are highly toxic to aquatic life and, if spray teams mix the chemical solutions or load their sprayers near water, or wash sprayers and discard empty insecticide containers into water (all common practice in poorly-supervised programs), fish kills and drinking water pollution can result. Methoprene, an insect growth regulator, has been identified as an alternate product for application to water to kill larvae.

New and traditional botanical and biological insecticides and repellents are being identified which are both effective and less toxic to humans and wildlife than the synthetic pesticides currently in use. Examples include formulations of the natural toxins of specific types of the insect-killing bacterium *Bacillus thuringiensis (B.t.)*, methoprene, a synthetic insect growth regulator that can be applied to water to kill mosquito larvae and is harmless to fish; the burning of cakes of the botanical pesticide neem inside homes as a mosquito repellent in India; and exploratory use of neem as a mosquito larvicide.

Alternative insecticides may be produced and deployed at the industrial or the artesanal level, depending on need and circumstances and with a view to opportunities for local income generation. The Onchocerciasis Control Programme developed an appropriate formulation of *B.t.* for aerial application by specialized staff against blackfly larvae throughout West Africa. In contrast, a program in Peru is using coconuts as a substrate for the village-level production and application of live cultures of *B.t.* to the breeding sites of malaria mosquitoes.[14]

3. Essential IVM Underpinnings

Most of the alternative malaria control projects that WWF chose to profile in this report, as well as many of the candidate case studies that were considered for profiling, fit the integrated vector management approach based on local analysis recommended by the Global Strategy for Malaria Control. It is striking, therefore, that a number of these projects have disappeared or languished instead of becoming instruments of constructive change.

If vector control programs are to improve, methods must be found not only to develop and evaluate new approaches through pilot projects but also to continue and expand pilot projects where appropriate, drawing on them for others.

As well, some malaria control programs appear to be so overstressed and underfunded just with traditional house spraying programs that they are unable to try new things. Another hurdle may be that most malaria-control decision makers have worked with the drugs/house spraying vector control strategy during their entire professional lives, and are doubtful of other approaches. Certainly most are relatively inexperienced with alternative vector control measures and meaningful community participation.

The result, noted in the Global Strategy document, is that "in some countries, … malaria control programs persist with inefficient practices based on eradication principles," and "… resistance to change is to be expected."

There is a clear need for outside impetus and technical and financial support to get on and move along the IVM spectrum for beneficial change. As the Global Strategy states, "Local situation appraisal and action need global support." The Onchocerciasis Control Programme and the series of internationally funded regional tsetse control projects that will blanket sub-Saharan Africa provide models of the kind of sustained regional, multi-sectoral effort that is necessary to meet broad-scale challenges.

Just as concrete tools and techniques definitely need to be available to and understood by the responsible agencies, adequate funding, strategic provision of information, skills, technology, and a commitment to an IVM approach are critical underpinnings of safer, cost-effective, community-grounded integrated vector management.

Research support

The successful tsetse control program in Botswana and the West African Onchocerciasis Control Program demonstrate the productivity of national level research supported by regional and international collaboration. National malaria control programs should look to those in Mexico and the Philippines, which seek to increase their collaboration with research scientists from a variety of disciplines. This provides an educational experience that can improve in-house operational research capacity.

Locally focused research should take a pragmatic, problem-solving approach in collaboration with NGOs and communities. Local action coalitions provide an attractive platform for research proposals aimed at a broad range of funding sources. Research should start before programs or projects begin operating. Planning should be based on a preliminary study of relevant local knowledge, attitudes, and practices, and a baseline profile of the disease situation that can be used to measure program impact later.

Institutionalization

As the profile of the Kheda project shows, care must be taken to institutionalize successful pilot initiatives as part of regular health care and vector control programs. Political support must be cultivated from the start for maintenance and scaling-up of effective programs. Adequate orientation, training, incentives, and supervision for local health officers and community members are also crucial.

Strong networking and coordination are necessary between local programs and between the national and local levels. Central support and leadership is required on an ongoing basis for troubleshooting and for ensuring that individual programs fit smoothly within the national health agenda. In addition, there must be a supportive regulatory and economic framework (subsidies, taxes, cost recovery), information dissemination, and a budget that supports effective implementation of those responsibilities.

Meaningful community participation

Increased community participation is a corollary of the decentralization of disease control programs and necessary for carrying out activities affordably and enhancing coverage. It is also essential for the sustainability of programs. Moreover, many vector-control approaches, such as biological control, environmental management, and bednets, are best implemented at the community level and with NGO support.

Agencies responsible for controlling vector-borne diseases must learn how to facilitate genuine community participation in planning, decision making, financial authority, operations, and evaluation. Appropriate health education and management training should be designed for empowering and motivating relevant sectors of the community. Social science expertise is important for community mobilization and good communication and evaluation.

Adequate funding for decentralized IVM activities

Decentralization of responsibility for malaria control should be accompanied by new funds to cover the additional expenses incurred by local health agencies. Insufficient funding hampered Mexico's initial decentralization attempt. Similarly, underfunding is producing an absence of commitment and low performance in local government health programs in the Chocó Department of Colombia, hampering effective implementation of a successful pilot malaria strategy that uses an IVM approach.[15]

While donor investment in malaria control has declined in the recent past (for example, USAID decreased funding for malaria research and field programs by 80 percent between 1985–1994), this picture may be starting to change. In 1997, the Multilateral Initiative on Malaria (MIM) was launched to bring attention to the malaria problem and to raise funding for locally sustainable malaria research and control programs in Africa.[16] UNICEF launched a major initiative with several facets, including making new drugs available on a wide scale and supporting bednet programs.[17] A number of donors are supporting a Task Force on Malaria Research Capability Strengthening, coordinated by the UNDP/World Bank/WHO Special Programme for Research and Training, which offers funding to strengthen and develop African research through partnership with non-African groups.[18,19] And, in March 1998, USAID announced a $50-million global attack on infectious diseases, including the promotion of bednets and methods for the early diagnosis and treatment of malaria.[20] An explicit focus on supporting a shift toward less pesticide dependence would do much to guide and advance IVM.

Attempts should also be made to find or create local sources of financial support and collaboration, such as NGO participation and co-financing by beneficiaries in the community or the private sector. Wherever possible, vector control should be linked to income generating activities such as the food fish and wood production that motivated residents of Kheda, India, to participate in malaria control initiatives.

Environmental/health partnerships

To date, national malaria control programs appear to have placed little weight on environmental considerations. For instance, although DDT's hazard to wildlife has been known for decades, neither the Mexican nor the Philippine malaria control programs which applied DDT routinely until recently, created special guidelines for vector control activities in areas of conservation value (i.e., close to national parks). Moreover, there appear to have been few investigations of the non-target and environmental impacts of vector control operations.

Sensitivity to environmental impacts should be institutionalized within vector control programs. For instance, the Scientific Environmental Monitoring Group that helps oversee the southern Africa Regional Tsetse and Trypanosomiasis Control Programme, and the Ecological Group within the Expert Advisory Committee of the Onchocerciasis Control Programme are responsible for the programs' minimization of adverse environmental impacts.

The potential environmental problems posed by vector control programs exceed the jurisdiction and capabilities of most Ministries of Health. There is a need for intersectoral collaboration between the conservation and health communities and the development, agriculture, and water supply sectors in order to have rounded participation in decisions about pesticide choice and management and implementation of non-chemical alternatives. Intersectoral collaboration must include the operational level of local programming, supported by similar cooperation at district, national, and international levels.

PART E

RECOMMENDATIONS

WWF's recommendations rest on the following premises:

1. Much disturbing information about the hazards of DDT to human health and global biodiversity has emerged since the WHO's last major assessment of DDT in 1993. These hazards are both local – for example, to breast-feeding infants in the tropics – and distant – for example, to Arctic foodwebs and the indigenous populations depending on them.

2. Affordable alternatives to DDT are available now, as illustrated by WWF's profiles in this report.

3. Reducing reliance on DDT should be part of a broader program of reduced reliance on synthetic chemicals. It should, therefore, be nested within a broader program of Integrated Vector Management and that, in turn, should rest within a broader public health program of Integrated Disease Management.

4. While synthetic pyrethroids for house spraying and impregnating bednets offer the benefit of low persistence and bioaccumulation relative to DDT, they pose other known hazards. In addition, some possible hazards of these chemicals – most particularly their possible impact in the womb on developing fetuses and embryos – have not been sufficiently characterized.

5. Breakthroughs in biochemistry and chemical engineering – especially the ability of scientists to rapidly assess new chemicals in the laboratory, decipher genetic codes, and engineer new molecules – increase the pace at which potential new vaccines and other non-pesticide-based approaches to disease control can be evaluated and deployed. However, the malaria parasite has proven to be a particularly difficult foe to combat, and it is not possible to predict when successful and sustainable drugs and genetically engineered remedies will be created.[1]

6. Increases in malaria resulting from human migration, war, and climatic factors such as rainfall and increasing temperatures may be unavoidable. But the impact of new irrigation and other development projects funded by aid agencies and national governments is manageable. As such, an integrated approach to disease management requires careful assessment of such projects' potential contribution to disease outbreaks and incorporation of mitigation measures at the project design stage.

7. Structural adjustment programs of international lending agencies and other international financial pressures are placing substantial pressures on developing nations' budgets. If malaria management programs are to have any chance of success in many countries, targeted financial assistance must be provided by donor nations.

WWF offers its recommendations at a time of renewed global interest in managing malaria, although the nature and organizational form of the global response to the malaria challenge remains fluid. The WHO, the World Bank, the privately funded Wellcome Trust, and other multilateral organizations are exploring new cooperative arrangements to plan and fund malaria research, in a confederation called the Multilateral Initiative on Malaria (MIM).[2] The World Bank's environmental health program has been growing dramatically, and includes an approximately $200-million malaria control project in India.[3] The Wellcome Trust, these other organizations, and British drug companies have attempted to stimulate contributions from other drug companies for a $180-million project to develop new treatments for malaria, but thus far have been rebuffed.[4]

The appointment of Dr. Gro Harlem Brundtland, well-known for her commitment to "sustainable development," as Director-General of the World Health Organization, may reinvigorate this widely respected and central agency.[5] Dr. Brundtland's concern for sustainability and inter-sectoral cooperation offers the potential for the WHO's partnerships with the World Bank and others to foster programs that simultaneously accomplish public health, biodiversity protection, and economic development goals.

Reliance on DDT can be further reduced, provided that there is concerted government and private sector action to achieve this goal. The international POPs treaty that will be negotiated is an essential step to help accelerate this process, but major commitments by other key decision makers are also necessary to accomplish this objective. Because phasing out DDT requires such a collaborative process, WWF directs its recommendations widely – at the negotiators of the international POPs convention, officials in multilateral organizations, bilateral assistance agencies, and national governments.

RECOMMENDATION #1: DDT should be phased out of use and ultimately banned.

a) Production and use of DDT should be banned globally by no later than 2007 under the auspices of the International Convention on POPs.

This deadline coincides with Mexico's commitment, pursuant to the North American Regional Action Plan for DDT, to end use of DDT. Mexico is one of the world's few producers of DDT and if Mexico is willing to make such a commitment, other nations should also be willing to do so.

b) In the interim, DDT should be characterized by the WHO and international assistance agencies as a pesticide of last resort, to be used only when no other vector control methods (including other pesticides) are available and likely to be effective.

The WHO and other organizations should take this step based on the additional evidence about the human and biodiversity impacts of DDT that has been gathered since the last major consideration of this issue by the WHO scientific experts in 1993. The result of this shift in characterization of DDT should place an increased burden of proof on malaria control program managers to demonstrate why they are using DDT in their disease interventions and identify alternatives.

RECOMMENDATION #2: Targeted programs promoting Integrated Vector Management (IVM) and Integrated Disease Management (IDM), which emphasize reduced reliance on pesticides and better environmental protection, should be developed by national health authorities, in collaboration with WHO, the World Bank, UNEP, and other multilateral and bilateral assistance agencies.

The WHO's 1992 Global Strategy for Malaria Control already emphasizes the major elements of IVM and IDM, although it does not use such terms *per se*. The four basic technical components of

the strategy are early diagnosis and prompt treatment; planning of *selective and sustainable* preventive measures, including vector control; early detection, containment or prevention of epidemics; and strengthening of local capacities in basic and applied research.

a) Each nation should have in place, by the year 2000, a plan to implement the 1992 Global Strategy for Malaria. Nations with plans should reassess and revise them to incorporate pesticide reduction measures, including elimination of reliance on DDT.

As of the end of 1996, 38 of the 46 malaria endemic countries in Africa had completed national plans of action for malaria control. Beyond Africa, 55 nations had created such plans.[6] Mexico, when it develops a detailed plan to accomplish its goal of elimination of DDT by 2007, might create a model useful for other nations. In much the same way it now exports DDT for use in other countries, Mexico might begin to export its expertise in how not to use DDT.

b) In and around conservation areas, organic agricultural areas, and habitat of vulnerable species, special emphasis should be placed on eliminating use of pesticides and special care should be exercised in the deployment of pesticides.

Agencies responsible for environmental and natural resources protection should be major players in the development of IVM plans. Attention to improved data gathering, mapping, and analysis ("stratification") that emphasizes the characterization of malaria regions by ecological type, vector dynamics, and human behavior, will assist in defining appropriate intervention methods.

c) Extreme caution should be taken to avoid adverse impacts on ecosystems and biodiversity.

Implementation of biological and environmental management methods should be undertaken carefully, after due preliminary research and planning to avoid or mitigate any undesirable conservation impacts.

d) Strong community participation and measures to prevent illegal use of DDT for non-public health uses must be components of IVM plans.

RECOMMENDATION #3: Adequate financial and technical resources must be earmarked toward operationalizing IVM.

Especially when promoting the decentralization of malaria management, newly empowered local agencies must not be given a mandate to operationalize their plans without the necessary financial and technical capacity, infrastructure, and commitment to community engagement.

In addition to collaborative efforts with national health agencies, donor agencies need to take into account their grant and lending policies in other sectors and ensure that economic development projects are not working at cross-purposes with disease reduction initiatives.

RECOMMENDATION #4: Pesticide manufacturers and public agencies should conduct collaborative research to analyze the possible hazards from chronic human exposure to synthetic pyrethroids used to spray residences and impregnate bednets.

The literature on insecticide-impregnated bednets and the use of synthetic pyrethroids for house spraying fails to mention possible trans-generational consequences of chronic human exposures. There is no indication in the scientific literature of modelling or monitoring studies addressing these issues. Absence of evidence does not mean absence of effect. Decisions about reliance on impregnated bednets and other public health approaches that would result in continuous human exposure to synthetic pyrethroid insecticides need to be fully informed by research that addresses these possible hazards.

PART F

ENDNOTES

Part A

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Part B

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WWF – known as World Wildlife Fund in Canada and the U.S. and World Wide Fund for Nature elsewhere – is an international network of 26 organizations dedicated to saving the diversity of life on Earth. Collectively the largest conservation organization in the world, WWF has sponsored more than 2,000 projects in 116 countries since its inception in 1961. There are approximately 4.7 million WWF members worldwide and nearly 1.5 million in Canada and the U.S. alone.

WWF is fully engaged in addressing the threats to the Earth's web of life by:

- preserving genetic, species, and ecosystem diversity;
- ensuring that the use of renewable natural resources is sustainable now and in the longer term, for the benefit of all life on Earth;
- promoting actions to reduce, to a minimum, pollution and the wasteful exploitation and consumption of resources and energy.

WWF's ultimate goal is to stop, and eventually reverse, the accelerating degradation of our planet's natural environment, and to help build a future in which humans live in harmony with nature.

In accordance with this mission, WWF's work to reduce pollution stems from the understanding that synthetic chemicals now contaminate every ecosystem of the globe and pose a threat to biodiversity, including humans. Research, policy reform, and public awareness efforts are directed at reducing the use of and reliance on chemical pesticides and other toxic chemicals. From new laws and policies to field-level changes in agricultural practices and best-selling books, WWF has been successful in working with governments, private corporations, farmers, other conservation, development and sectoral organizations, and the general public to raise awareness about and gain tangible action toward pollution prevention.

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