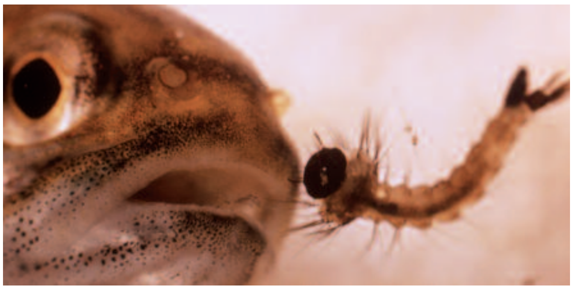
PAN Germany
Pestizid Aktions-Netzwerk e.V.

Environmental strategies to replace DDT and control malaria



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Nernstweg 32, 22765 Hamburg
Tel. +49 (0)40 - 399 19 10 - 0
E-mail: info@pan-germany.org
www.pan-germany.org

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Author: Vanessa Laumann
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Preface

In 1985 Pesticide Action Network (PAN) International published a »Dirty Dozen« list of particularly hazardous pesticides. In targeting these chemicals and highlighting their adverse effects, PAN initiated a process for strict controls, bans and ultimate elimination of these and other pesticides that endanger health or the environment. The »Dirty Dozen«, which included DDT, was carefully chosen to provide examples of negative impacts – such as acute poisonings, reproductive effects, cancer or endocrine disruption – of different pesticides. This successful campaign has contributed to a considerable reduction in the use of the listed pesticides, and many are now globally banned. In spite of its known hazards, many countries still use DDT in the fight against malaria. According to the legally binding Stockholm Convention on Persistent Organic Pollutants (POPs), which became effective 2004, the use of DDT must be reduced and ultimately eliminated. A study by PAN Germany, »DDT and the Stockholm Convention – States on the edge of non-compliance« (PAN Germany, 2009), has shown that the actions to reach this goal are insufficient.

But what alternatives to DDT are available? Governments are faced with two options for malaria vector control: either to use alternative pesticides to DDT or to implement a range of integrated measures largely based on non-pesticidal approaches. The number of pesticides approved by the World Health Organisation for use against mosquitoes is limited, leading to problems of resistance and ineffective spray regimes. As shown in this study, many of these approved alternatives to DDT are also highly hazardous.

Malaria control programmes need to expand the range of public health measures at their disposal and adopt approaches that will avoid the potential adverse health and environmental impacts from pesticides. These approaches can also contribute to rolling back other diseases.

This study examines the problems of malaria. It identifies options for non-pesticidal interventions largely incorporating environmentally-based strategies. Six case studies provide examples of successful alternative strategies from different continents.

Messages from the field indicate that political will and engaging the affected communities in control actions are essential ingredients for a safer and more effective malaria control strategy. The experiences presented here demonstrate that less hazardous approaches to malaria control are possible. Many scientists, politicians, community and village health workers, community groups, funding agencies and foundations already contribute to the implementation of low-risk malaria control approaches as an alternative to DDT, and some have been a valuable source for this study.

We want to thank all those who have contributed to this study, particularly Charles Mbogo, Henk van den Berg, Jorge Méndez-Galván, Andrea Brechelt and Barbara Dinham. We hope that this study stimulates readers to join the promising efforts to further develop and implement safer approaches to malaria control.

Carina Weber
(Director, PAN Germany)

Summary

Malaria is one of the major global health problems and has a devastating impact on many populations, particularly in Africa. The main tools and strategies currently employed to control malaria are medicines for its prevention and treatment, and chemicals to control the mosquito vectors.

Chemical strategies focus on insecticide treated nets and indoor residual spraying. But these chemical applications pose established and suspected risks for human health and the environment. Medical and chemical approaches can become ineffective through development of resistance – by mosquito vectors to chemicals and by parasites to pharmaceuticals. The widely-banned pesticide DDT is still used in many countries to control the vectors of malaria, even though the legally binding Stockholm Convention on Persistent Organic Pollutants (POPs) calls for its global elimination.

An alternative for reducing the incidence of malaria lies in the development of integrated strategies systematically based on social and ecological approaches. This study sets out the importance of analysing a specific situation in order to develop a holistic strategy of interventions which will be appropriate to the vectors and the local conditions. The strategies proposed recognise the importance of community participation, health education, surveillance, improving public health systems, decentralization of malaria control implementation, local capacity building, income generation, involvement of civil society organisations, support of local research, intersectional and regional cooperation.

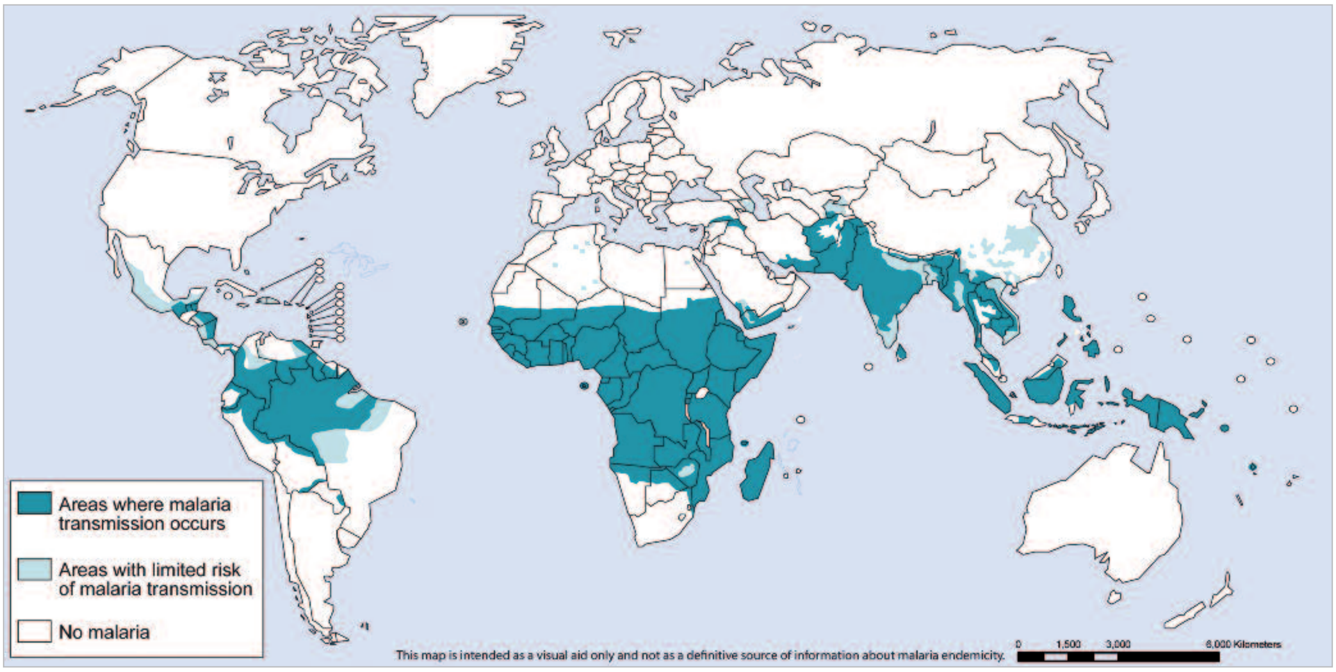
The study presents examples of successful interventions that do not depend on pesticides. The Zambian and Mexican experience demonstrates how environmental management strategies can be successful. Pilot projects in rural and urban sites in Kenya and Sri Lanka demonstrate success with bioenvironmental malaria control. Programmes in Vietnam and Mexico show that it is possible to phase out dependence on DDT, reduce reliance on pesticides and bring down malaria rates.

Efforts to develop alternative tools to complement and replace insecticide-based vector-control strategies must be developed, strengthened and implemented. They can reduce the burden of malaria and simultaneously produce many benefits. The positive aspects of ecological strategies include sound protection of the environment and human health, enhanced general health status, long-term sustainability and contribute to rural development.

Malaria – A deadly disease

Malaria is an infectious parasitic disease which has been a deadly human companion for millennia. As populations migrated from tropical Africa into Eurasia and later across the ocean to the Americas, malaria parasites moved with their human hosts. Malaria became a worldwide disease. At the turn of the twentieth century 77 percent of the global population was at risk of malaria. During the twentieth century, efforts to control malaria restricted its distribution, so that by 1994 the percentage of the global population at risk had decreased to 46 percent (Figure 1). However, massive population growth meant that the absolute number of people exposed to malaria had increased dramatically, particularly on the African continent. Today, three billion people – almost half the world population – are at risk of infection in 109 malarious countries and territories. This results in around 250 million cases and approximately one million deaths annually. Malaria may cause miscarriages, and infected women are at risk of bearing low birth weight babies, who in turn are at increased risk of premature death. An estimated 85 percent of malaria deaths occur among children under five. Malaria is now prevalent in tropical and subtropical regions and is thus regarded as a »tropical disease« with the vast majority of cases occurring in Africa. [1, 2, 3, 7]

(Figure 1) Global distribution of areas where malaria transmission occurs in 2008. Source: World Health Organisation (2008)



The term *malaria* (from the Italian *mala aria* meaning foul air) bundles together the disease consequences of mainly four parasites. Two of them are by far the most important: *Plasmodium (P.) falciparum* and *Plasmodium vivax*. All parasites produce fevers and anaemia. *P. vivax malaria* produces temporary debilitation during the course of and in the aftermath of the fever. The death toll of *P. vivax* is estimated at perhaps 1 – 2 percent of those with severe untreated infections during epidemics. This infection can result in relapses many months or even years after an apparent cure due to a dormant liver stage. *P. falciparum* malaria can bring about severe anaemia and if untreated can produce cerebral malaria which may lead to coma and death. Without medical care death toll of *P. falciparum* cases among infected non-immune people is estimated to range between 25 and 50. It is responsible for almost all deaths from malaria.[3]

The understanding of the epidemiology of malaria has changed dramatically over the last century with significant implications for mosquito control practices. In western pharmacology the bark of the cinchona tree, which contains the alkaloid quinine, was used to treat *P. falciparum* for centuries, and from the nineteenth century quinine * was the first disease specific drug. Strategies to reduce malaria by environmental control of mosquito breeding sites opened up following some important discoveries: in 1880 Alphonse Laveran, a French military physician, identified parasites in the blood of malaria patients. In 1897, Ronald Ross concluded that the mosquito was the vector for malaria. In the same year, Grassi proved that the female *Anopheles* mosquito was the vector for human malaria. These findings led to some targeted vector control interventions, for example in the Panama Canal, Indonesia, Malaysia and the Zambian copper belt. By manipulating the breeding environment, malaria was effectively reduced. In the first half of the twentieth century malaria was eliminated from the United States and most of Europe by improving environmental and social conditions, including changes in land use, agricultural practices and house construction. These gains often coincided with economic and social developments.

In the 1950s and 1960s, the Global Eradication Campaign, spearheaded by the World Health Organisation (WHO), integrated the use of the insecticide dichlorodiethyltrichloroethane (DDT), first synthesized in 1874, into its programme. The strategy depended on chloroquine for treatment and prevention and DDT for vector control, whereas environmental management activities almost disappeared. Initially, the campaign was very successful but the programme could not be sustained. The cost was high, many communities objected to repeated spraying of their houses, and resistance emerged to chloroquine among *Plasmodium (P.)* parasites and to DDT among *Anopheles (A.)* mosquitoes. Global eradication was officially abandoned in 1972. Since then, the burden of malaria has increased substantially in many parts of the world and its eradication remains elusive.[2, 3, 4, 7]

Today, many tools – biological, environmental, chemical and medical – exist to combat malaria but an environmentally safe, healthy and sustainable strategy remains a challenge. Strategies are overly-reliant on chemical-based interventions.

* Quinine attacks only the merozoite stage of the malaria parasite and does not eliminate the gametocytes. Therefore, it reduces just the symptoms and does not prevent humans from being infected.[7]

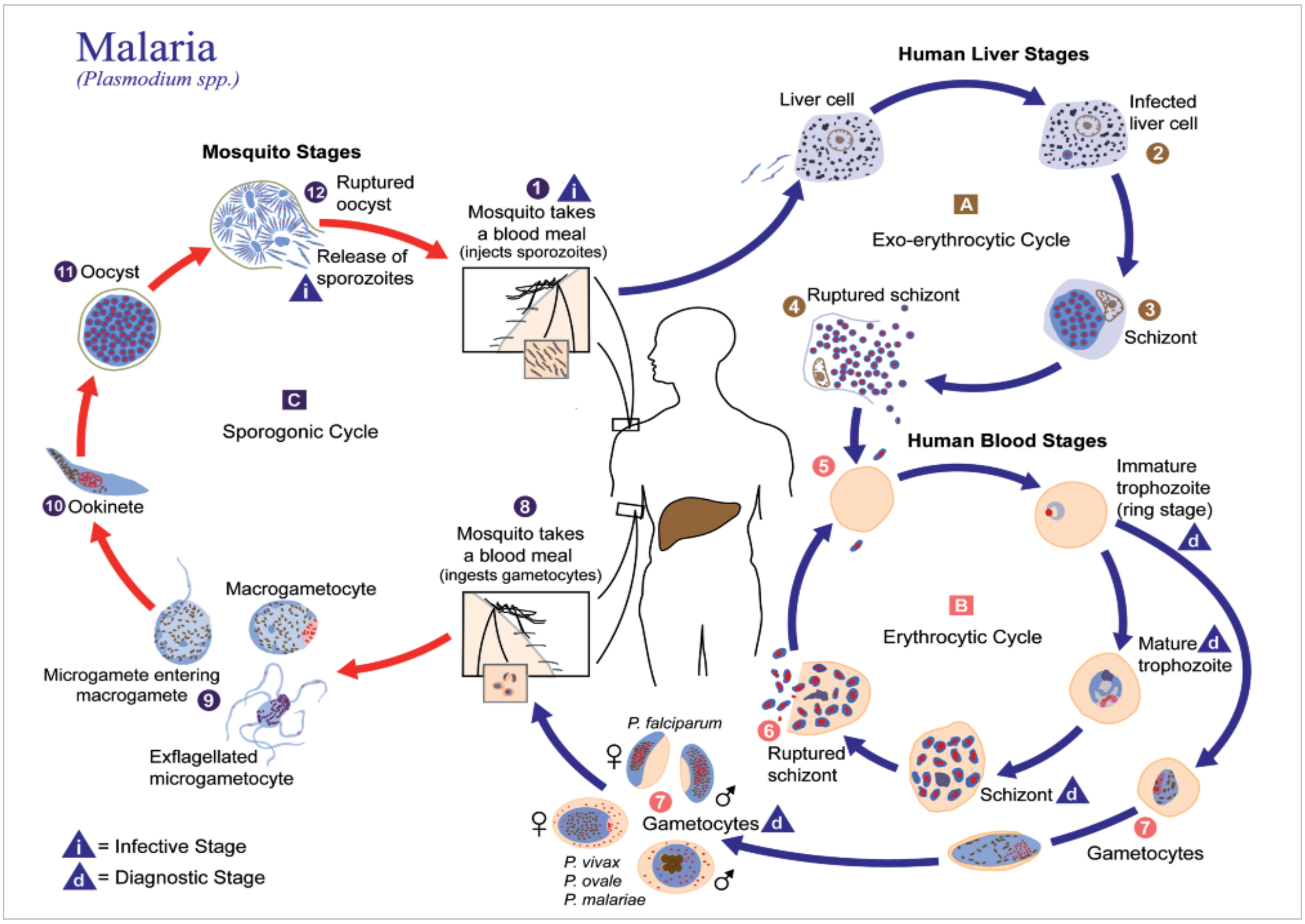
Parasites and vectors – Favourable conditions increase populations

Malaria is a highly complex disease caused mainly by four parasites (*P. falciparum, P. vivax, P. malariae, P. ovale*) and vectored by a large number of anopheline mosquito species. Malaria epidemiology depends on many factors including the environment (climate, topography, hydrology and housing); human actions (land use and occupation, daily activities and habits, migration); malaria prevalence; and entomological factors (density, flight range, breeding, feeding and resting habits of mosquitoes, infection rate).[5]

Malaria infections are a consequence of an intricate series of ecological interactions between malaria parasites, mosquitoes and humans (Figure 3). The infection of the human host with a *Plasmodium* parasite begins with the bite of an infected *Anopheles* mosquito (Figure 2). Adult females require blood meals for egg production. Sporozoites are transmitted via the saliva of a feeding mosquito; they rapidly access the human blood stream and enter the host's liver. The asymptomatic liver stage usually lasts about five to six days. After cellular division merozoites generate and invade the blood. Repeated cycles of multiplication take place in red blood cells, destroying invaded cells and infecting others. Periodic blood cell invasion and bursting every two or three days produces the classic human malaria symptoms of recurrent fevers and chills. Some merozoites develop into gametocytes, which can be ingested by a feeding mosquito where they

(Figure 2) Female *A. freeborni* taking a blood meal from a human host.
Source: CDC/James Gathany (2004)

(Figure 3) Life cycle of *Plasmodium*. Source: CDC/Alexander J. da Silva, PhD Melanie Moser (2002)



again develop into infective sporozoites. The mosquito becomes infectious to its next blood meal donor approximately two weeks – depending on temperature – after ingesting gametocytes.[4, 6, 7]

The parasites have different temperature requirements for reproduction within the mosquito host. *P. vivax* has adapted to the widest range of temperature and can extend its seasonal reach into the Arctic although temperatures must exceed 15°C for at least a month. *P. falciparum* does not reproduce when the temperature drops below 19°C. It is the dominant parasite in sub-Saharan Africa.[3]

About 40 anopheline mosquito species can transmit malaria. All mosquitoes require water for their larvae development. The species' preferences for breeding habitats vary considerably and can be highly selective. Major factors are shade or sun exposure, still or flowing water, temperature, salt content, surface vegetation, floatability and organic pollution. Mosquitoes breeding in the tropical zone in water temperatures of 23 – 27°C usually complete their aquatic growth within two weeks. The behavioural patterns of adult mosquitoes also vary between species. Most mosquitoes of tropical species fly within a range of 1 – 3 km. Some species fly and feed between the hours of dusk and dawn when the air is humid; others fly and feed during daytime hours. Usually, mosquitoes enter houses to feed in the early hours of the night. Mosquitoes resting indoors are termed endophilic (Box 1) and those feeding indoors are termed endophagic. Mosquitoes which prefer humans as a source of blood are called anthropophilic and animal-feeders are termed zoophilic. Exophilic mosquitoes rest outdoors using sheltered places or plants for breeding and resting sites. After entering houses endophilic mosquitoes rest for 2 – 3 hours and remain indoors for a further 24 – 48 hours until the blood has been digested and the ovaries contain mature eggs. They then leave the house in search of a suitable aquatic site for egg deposition.[6]

Broadly, there are three distinctive requirements for the transmission of malaria:

- a critical level of population density
- a critical percentage of permanently parasitized individuals as a reservoir of *plasmodia*[8]
- zones of endemic infection of a temperature and altitude to maintain the presence of mosquitoes (disease density)[3]

As an example, in sub-Saharan Africa the main vectors *A. gambiae* and *A. funestus* are very efficient malaria vectors because they have relatively high anthropophily, longevity and density. Malaria transmission intensity is highly variable but the average annual rate at which people are bitten by infectious mosquitoes is estimated at 121 infected bites per person a year in Africa.[2] In some places, it is not unusual to find several hundred mosquitoes in one room during a single night, 1 – 5 percent of which are infectious.[9]

Many tools exist to control malaria and to attack the parasite at different stages of its life cycle. But it is important to understand the epidemiology of malaria, which depends on the biology and ecology of local vectors, the distribution and behaviour of people and environmental conditions. Analysis of the local situation is essential in order to develop a holistic strategy of interventions for effective and sustainable malaria control appropriate to conditions and vectors.

(Box 1) **Mosquito behaviour:**

Endophilic	rest indoors
Exophilic	rest outdoors
Endophagic	feed indoors
Exophagic	feed outdoors
Anthropophilic	prefer human blood
Zoophilic	prefer animal blood

The current anti-malaria approach

After the failure of the global malaria eradication programme interest in malaria was reduced until the late 1990s. Industry lost its interest in supporting research on insecticides and drugs and national malaria control programmes collapsed in many malaria endemic countries.[9] In 1998 the »Roll Back Malaria« initiative was launched comprising more than 500 partners: international organisations including the World Health Organisation (WHO), the World Bank, UN Environment Programme (UNEP) and UNICEF; representatives of endemic countries and their partners; the private sector; non-governmental and community-based organisations; foundations; and research and academic institutions. Initiatives for drug discovery, vaccine development and increased financing of control efforts were launched including the Multi-lateral Initiative on Malaria, Medicines for Malaria Venture and the Malaria Vaccine Initiative. Major financial support came forward from the Global Fund to Fight AIDS, Tuberculosis and Malaria, the World Bank and the US-American President's Malaria Initiative. At the 2000 Abuja Summit African governments set goals to achieve large improvements in malaria treatment and prevention. Since then, malaria control has intensified in endemic countries, supported by the increased investment of financial resources and technical assistance from the international community.

The Roll Back Malaria initiative aims at halving the number of deaths from malaria by 2010. The long term global strategy again aims to eliminate malaria worldwide. Roll Back Malaria has identified the following targets to realise this ambition: 80% of people at risk from malaria are using locally appropriate vector control methods such as long-lasting insecticidal nets, indoor residual spraying and, in some settings, other environmental and biological measures; 80% of malaria patients are diagnosed and treated with effective anti-malarial treatments in areas of high transmission, 100% of pregnant women receive intermittent preventive treatment. A focus is on malaria in the highly endemic areas of sub-Saharan Africa where the global burden is highest.

Currently, the main methods for malaria control are insecticide-treated nets, indoor residual spraying of pesticides, chemotherapy (pharmaceutical treatment) and chemoprophylaxis (prophylactic use of pharmaceuticals) (Figure 4, Box 2) and the Global Action Plan of Roll Back Malaria promotes the further scaling-up of these interventions.

(Figure 4) Main current malaria interventions:

1 Chemoprophylaxis (Malarone®)
2 Indoor Residual Spraying in Ethiopia
Source: Bonnie Gillespie (2007)
3 Insecticide-Treated Net in Africa
Source: P Skov Vestergaard Frandsen (2007)

(Box 2) **Main methods for malaria control in current practice**

Insecticide-Treated Nets (ITNs)
Since the 1990s, insecticide-treated bednets have been regarded as the most powerful malaria control tool. Two categories are available: conventional treated nets which need regular treatment – an action which has proven to be difficult at field level; and Long Lasting Insecticide-treated Nets (LLINs), a new technology which retains its efficacy for at least three years. Only pyrethroid insecticides are recommended for use in ITNs. The WHO reports big increases in the supply of mosquito nets, especially LLINs in Africa. But the number available in 2006 was still below demand.[1] LLINs are effective in highly endemic settings, particularly for infants and young children before they have acquired a certain level of natural immunity. But ITNs reduce acquired immunity and, in the case of interrupted use, result in increased vulnerability.[3] Concern about the sustained effectiveness of ITNs due to pyrethroid resistant vectors was sparked by a study in Benin where ITNs lost their efficacy.[10]

Indoor-Residual Spraying of insecticides (IRS)
The application of residual insecticides on all surfaces inside habitations irritates and kills exposed mosquitoes. Twelve insecticides are recommended by WHO for IRS in vector control, with DDT and pyrethroids thought to be the most cost-effective. However, resistance to DDT and pyrethroids is widespread and cross-resistance between these chemical classes severely limits the choice of insecticide. Since the WHO promoted the wider application of IRS in highly endemic areas of tropical Africa in 2006 several countries have been expanding these programmes. The WHO reports that IRS is used in all regions of the world and more than 70 percent of households at any risk of malaria are covered in some countries (Botswana, Namibia, Sao Tome and Principe, South Africa and Swaziland).[1]

Chemotherapy (pharmaceutical treatment)
Throughout the 1960s and much of the 1970s and 1980s chloroquine was an effective treatment against malaria. Resistance has been reported since the 1960s. Malawi became the first African state to replace chloroquine with sulfadoxine and pyrimethamine. Today, the WHO recommends the treatment of a *P. falciparum* infection with an Artemisinin-based Combination Therapy (ACT) and *P. vivax*, except where it is resistant to chloroquine, with chloroquine and primaquine.[1]

Chemoprophylaxis (pharmaceutical use for prevention)
In areas of high transmission WHO recommends the administration of intermittent preventive treatment (IPT) with sulfadoxine-pyrimethamine. It should be administered to pregnant women at least twice during the second and third trimesters of pregnancy, and three times in the case of HIV positive pregnant women. IPT could also be administered to children. Its effectiveness should be monitored in light of increasing resistance.[1] Currently, no serious adverse effects have been reported during trials of chemoprophylaxis in children, but the possibility that occasional serious adverse effects may have been missed cannot be excluded and need further surveillance.[11]

These chemical and pharmaceutical interventions pose established and suspected risks for human health and the environment.

List of pesticides recommended for malaria control – A list of concern

All but one of the pesticides recommended by WHO for IRS and ITNs to control malaria are on the PAN International List of Highly Hazardous Pesticides. The PAN List of Highly Hazardous Pesticides is based on widely accepted standards and can be found at http://fao-code-action.info/action_centre.html (see below, »Spotlights«). The following overview indicates reasons for concern associated with these pesticides and the value of adopting non-chemical approaches wherever and whenever possible.

(Table 1) List of pesticides recommended for malaria control, hazard indications

WHO recommended pesticides	WHO recommended IRS dosage[12]	WHO estimate of duration of effective action[12]	Reasons for listing at PAN International List of Highly Hazardous Pesticide[13]
Alpha-cypermethrin (pyrethroid)	0.02 – 0.03 g/m²	4 – 6 months	• Highly toxic to bees[14]
Bendiocarb (carbamate)	0.1 – 0.4 g/m²	2 – 6 months	• Highly toxic to bees[14]
Bifenthrin (pyrethroid)	0.025 – 0.05 g/m²	3 – 6 months	• Highly toxic to bees[14] • US EPA: Possible human carcinogen (Group C) • EU: At least one study providing evidence of endocrine disruption in an intact organism* • Highly bioaccumulative[15] • Very persistent in water/sediment[16]
Cyfluthrin (pyrethroid)	0.02 – 0.05 g/m²	3 – 6 months	• Highly toxic to bees[14]
Deltamethrin (pyrethroid)	0.01-0.025 g/m²	2 – 3 months	• Highly toxic to bees[14] • EU: At least one study providing evidence of endocrine disruption in an intact organism*
DDT (organochlorine)	1 – 2 g/m²	> 6 months	• EU: At least one study providing evidence of endocrine disruption in an intact organism* • US EPA: Probable human carcinogen (Group B2) • IARC: Possibly carcinogenic to humans (Group 2B) • EU Directive 67/548: Substance which causes concern for humans owing to possible carcinogenic effects (Category 3) • POP pesticide[17] • PIC pesticide[18]
Etofenprox (pyrethroid)	0.1 – 0.3 g/m²	3 – 6 months	• Highly toxic to bees[14]
Fenitrothion (organophosphate)	2 g/m²	3 – 6 months	• Highly toxic to bees[14] • EU: At least one study providing evidence of endocrine disruption in an intact organism*
Lambda-cyhalothrin (pyrethroid)	0.02 – 0.03 g/m²	3 – 6 months	• Highly toxic to bees[14] • EU: At least one study providing evidence of endocrine disruption in an intact organism* • EU (Directive 67/548): Very toxic by inhalation (R26)
Malathion (organophosphate)	2 g/m²	2 – 3 months	• Highly toxic to bees[14] • US EPA: Suggestive evidence of carcinogenicity but not sufficient to assess human carcinogenic potential • EU: Potential for endocrine disruption (ED), *in vitro* data indicating potential for endocrine disruption in intact organisms, also includes effects *in vivo* that may or may not be ED-mediated, may include structural analyses and metabolic considerations
Pirimiphos-methyl (organophosphate)	1 – 2 g/m²	2 – 3 months	• Not listed as Highly Hazardous Pesticide according to PAN
Propoxur (carbamate)	1 – 2 g/m²	3 – 6 months	• US EPA: Probable human carcinogen (Group B2)

* Not a formal weight of evidence approach

Non-pesticidal interventions

Current practice for malaria control is based on the rapid treatment of cases with effective anti-malarials and the protection of individuals from mosquito vectors using insecticide-treated nets or indoor spraying of insecticides. The strategy relies heavily on chemical pesticides and their efficacy is undermined by the development of vector resistance, vector behavioural adaptations, logistics and funding problems. Furthermore, pesticides pose established and suspected hazards to human health and the environment. The 1992 *Rio Declaration on Environment and Development (Rio Declaration)* calls for mitigating risks and the World Health Assembly 50.13 (1997) calls on governments »to take steps to reduce reliance on insecticides for control of vector-borne diseases through promotion of integrated pest management approaches in accordance with WHO guidelines, and through support for the development and adaptation of viable alternative methods of disease vector control«. The Stockholm Convention on Persistent Organic Pollutants calls for reduced reliance on DDT for vector control with the »goal of reducing and ultimately eliminating the use of DDT«.

Many vector control interventions exist and have proven to be effective, comprising environmental management including personal protection, biological and chemical measures.[19, 20, 21]

This report emphasises non-pesticidal interventions. These are frequently neglected even though they appear to be safe to humans, environmentally sound, relatively cost-effective, locally available and sustainable in comparison to chemical tools which are widely adopted.

Environmental management

Environmental management is defined by the WHO as »the planning, organisation, carrying out and monitoring of activities for the modification and/or manipulation of environmental factors or their interaction with man with a view to preventing or minimizing vector propagation and reducing man-vector-pathogen contact.« There are three categories: environmental modification; manipulation to target the larval stages of the mosquito life-cycle; and non-pesticidal personal protection (Box 3).[6]

(Box 3) **Environmental management**
- Environmental modification (e.g. land levelling)
- Environmental manipulation (e.g. intermittent irrigation)
- Personal protection (e.g. house improvement or bednets)

Environmental modification aims to create a permanent or long-lasting effect on land, water or vegetation to reduce vector habitat. It has been successfully implemented in large scale interventions in Panama, Italy, Malaysia, Indonesia, the Tennessee Valley of the US and the Zambian copper belt (Section 6, Page 19). In Zambia for example, draining wetlands by the creation of ditches or drains (Figure 5, Figure 9), land levelling, filling depressions or covering water tanks and stagnant water were among the approaches applied to prevent, eliminate or reduce the vector habitat. Initially, these interventions required significant costs but they contributed to the reduction or elimination of mosquito breeding habitats.[22] Any such interventions should be critically evaluated to protect biodiversity as large-scale draining projects could adversely affect natural wetland, ecosystems that are in decline worldwide.[5] Several pilot projects have recently been initiated to implement more sustainable and less pesticide-intensive approaches. Small-scale modifications that concentrate on human-made breeding habitats, have been successfully put in place in combination with other interventions, for example: in Uganda filling puddles[23]; in Kenya drying out stagnant pools (Section 6, Page 21); in Sri Lanka covering water containers (Section 6, Page 22); and in India filling pits[24]. On the other hand the development of irrigation schemes and construction of dams can increase the risk of malaria transmission. Risks have to be evaluated at the design stage to mitigate or avoid them.[25] Reduction of mosquito breeding sites can be achieved through planting trees with high water requirements. Planting local water-intensive tree-species like eucalyptus can help to reduce the surface water (e.g. in Kitwe, Zambia[26]) and create a source of income for local people (e.g. in Kheda, India[24]). However, these interventions should also be critically evaluated to protect biodiversity. Polystyrene beads have been used to prevent mosquito breeding in small confined water collections by hindering larvae respiration and preventing adult mosquitoes from laying their eggs on the water surface (e.g. in Kheda[24]).[27]

(Figure 5) Reconstructing a drainage canal in order to provide a permanent waterway promoting the free-flow of water through a malaria-prone (1981). Source: CDC

Environmental manipulation refers to activities that reduce larval breeding sites through temporary changes. The regular clearing of vegetation from water bodies or – depending on the vector species – elimination of shade or planting of shade trees may prevent egg deposition (vegetation management). Flushing streams[28, 29], periodically changing the water level of reservoirs or changing water salinity can eliminate breeding sites, but the impact on non-target organisms must be critically evaluated[6]. Malaria epidemics associated with irrigated rice lands can be minimised by introducing intermittent irrigation to control breeding sites (e.g. in Sri Lanka, Kenya[35], and China[30]). Periodic draining of the fields prevents the mosquito larvae from completing their development cycle and may increase the crop yield (water management). Environmental manipulation is best implemented at the community level with assistance from educational institutions.[5]

Non-pesticidal personal protection strategies for malaria prevention have historically been practised, particularly by locating houses away from breeding sites to reduce the human-vector contact. A distance of 1.5 to 2 km from major breeding sites may significantly reduce transmission.[6]

Female *Anopheles* mosquitoes are attracted by the exhalation of carbon dioxide and other human odours and they can be discouraged by improved ventilation, effective rubbish disposal strategies and setting aside a defined space for domestic animals.[87] Modification of human habitation has been shown to reduce the risk of malaria. In Sri Lanka poorly constructed houses were found to harbour significantly higher numbers of mosquitoes.[31] Screens can prevent mosquitoes entering houses. Mosquito nets can reduce the human vector contact and provide, even untreated, a certain degree of protection against malaria infection.[32] Covering eaves and repairing cracks and holes may reduce transmission. Clearing vegetation around houses may remove the breeding and resting sites of mosquitoes. Personal protection can be achieved through the use of long sleeved shirts and pants as well as repellents – the most universal of mosquito control practices to deter nuisance bites. Some societies use smoke. Some communities have built their houses on stilts, above the flight patterns of mosquitoes.[3] Domesticated animals can reduce the malaria cycle of infection through a process called zooprophylaxis (parasites die when an infected mosquito injects parasites into the bloodstream of an animal), but livestock may also increase the density of mosquito populations. This increase has been documented in a few areas where livestock are kept in a compound where people sleep outside.[3, 33]

Biological control

(Box 4) **Biological control**
- Bacterial larvicides (e.g. *Bti/Bs*)
- Predators (e.g. larvivorous fish)
- Botanicals including repellents, larvicides (e.g. neem), biological insecticides and medicinal herbs
- Nematodes
- Fungi
- Aquatic plant *Azolla*
- Sterile mosquitoes

Biological methods of malaria control use natural enemies of mosquitoes and biological toxins to suppress the vector population. The principal biological control agents are predators, particularly fish and the bacterial pathogens *Bacillus thuringiensis israelensis (Bti)* and *Bacillus sphaericus (Bs)*. Other promising organisms include fungal pathogens, nematodes and the aquatic plant *Azolla*. (Box 4)

Natural toxins of *Bti* and *Bs* are lethal to larvae of many mosquito species. Different formulations of *Bti* have been found effective against larvae of mosquitoes like *A. albimanus* or *A. gambiae*. These formulations are innocuous to most non-target aquatic organisms and to vertebrates. They constitute environmentally safe larvicides.[5] Commercially available strains of *Bti* for use against mosquito larvae are manufactured in the United States, Canada, Russia, India and Cuba and are sold under the trade names e.g. Aquabac® or Vectobac®.[5] The first production facility in Africa has been installed by the International Centre for Insect Physiology and Ecology at Nairobi (ICIPE).[22] Typically, pellets or liquids are distributed on the surface of stagnant water (Figure 6). Depending on the environmental conditions *Bti* may remain effective from 24 hours to over one month.[34] *Bti* is an important part of mosquito control in the United States, but is not part of large-scale malaria control operations in other countries.[5] Recently, its application has proven to be effective in the Mwea Irrigation Scheme[35], in Mbita,[36] Malindi (Kenya, Section 6, Page 21) and Dar es Salaam (Tanzania)[37].

Larvivorous fish have been used for mosquito control for at least 100 years. *Gambusia*, guppies, *Tilapia* and carp, among others, feed on the aquatic larval stages thereby decreasing the abundance of mosquitoes (Figure 7). Fish are a safe and inexpensive malaria control option that can be easily introduced in defined breeding sites.[38] In Betul (India) *Gambusia* was introduced into small and large ponds.[39] Guppies were used in Kheda (India).[24] Fish were effective in storage area and containers in Sri Lanka[73], in brick pits in Uganda[23] and in rice fields in China[40]. Furthermore, fish farming can provide economic, agricultural and nutritional benefits for the local population. Use of exotic predators should be avoided or critically evaluated to protect biodiversity and prevent displacement of native fish, as has occurred with the introduction of *Gambusia* to certain habitats.[5]

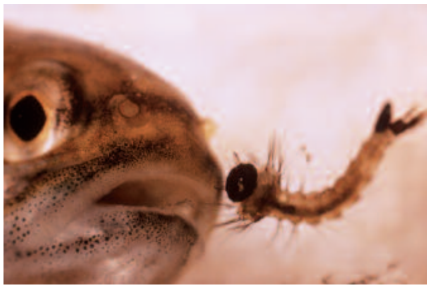
Several plants are significant botanical repellents of mosquitoes. This involves use of either live-potted plants or thermal expulsion from a source of heat.[41] Products of the neem tree have been shown to exhibit a wide range of effects on mosquitoes. Neem oil extracted from its seeds has repellent properties and has been successfully tested as a biolarvicide for anopheline mosquito control.[42] Citronella is most commonly found in herbal insect repellents. Its efficacy is comparable to that of the chemical repellent DEET (*N,N-diethyl-meta*-toluamide), but it provides shorter protection time.[43] Neem oil and citronella oil mixed with coconut oil as the main inert ingredient is effective, showing results against the most common adult mosquitoes and offering protection against the sun.[44]

Products based on natural pyrethrum, correctly applied, can be used to control adult mosquitoes without negative effects on human health. However the high price of the raw material, which is mainly produced in Kenya, makes the products too expensive for common use in tropical countries.[44]

Traditional medicines have been used to treat malaria for thousands of years, for example the modern drug ACT is derived from a medicinal herb (*Artemisia annua*), and *Euphorbia hirta* (Figure 8) found in tropical areas exhibits antimalarial activity.[45]

Protozoa, nematodes, fungi and the aquatic plant *Azolla* have all shown promise as a means of controlling mosquito populations under experimental conditions.

(Figure 6) Applying Bacillus thuringiensis to kill anopheline larvae (2006). Source: Mbogo



(Figure 7) *Gambusia* preparing to eat a mosquito larva (1976). Source: CDC

(Figure 8) Euphorbia hirta in Kenya (Malaria drug), 2006. Photo: Weber

Nematodes have shown potential to reduce mosquito larvae.[46] Certain fungal pathogens can be used on indoor surfaces of houses against adult mosquitoes.[47] A jumping spider, *Evarcha culicivora*, might have a role in efforts to control malaria; this naturally occurs around Lake Victoria (Uganda, Kenya) and chooses as preferred prey the blood-carrying female *Anopheles* mosquito.[48] Finally, the development of the first transgenic mosquito was announced in 2000. The manipulation of genes has created sterile mosquitoes* or mosquitoes with an altered choice of blood target from man to animal. Another approach has engineered malaria-resistant mosquitoes. But the release of transgenic mosquitoes into the wild is unlikely to occur for another 10 – 20 years and its impact must be fully evaluated.[49]

In summary, a wide range of non-pesticidal methods may be used to control malaria vectors. The interventions should match the specific local ecological, epidemiological and environmental conditions for successful implementation. Several environmental management techniques have been successful, particularly in the early 20th century. Non-pesticidal interventions are most effective when combined with improved surveillance, use of anti-malarial drugs, education and community involvement, although their systematic review has been limited. They require thorough preparation and perseverance. While being cost effective in the longer term, they produce relative high initial costs.[50] As a consequence, current implementation is rather limited. But concerns with the use of chemicals in relation to sustainability, human health and environmental impacts have encouraged pilot projects for lower pesticide-intensive approaches. Their successful implementation is presented in the next section.

* Insects can also be sterilized with radiation (sterile insect technique).

Messages from the field

Reports on recent progress in the control of malaria (including the World Malaria Report 2008) focus mainly on chemical interventions such as indoor residual spraying, and insecticide-treated nets, as well as the use of antimalarial drugs for therapy or as a prophylactic.

Studies demonstrate that the burden of malaria was recently reduced by 50 percent or more in Eritrea[51], Rwanda, Sao Tome and Principe and Zanzibar[52] mainly due to the high coverage of insecticides, impregnated bednets and the use of ACTs.[1] A high coverage of LLINs in Niger, Kenya, Rwanda, Ghana, Zambia and Ethiopia resulted in effective control of malaria.[53, 54, 55, 56, 57] Widespread application of indoor residual spraying in Mozambique, South Africa and Swaziland led to observed declines in malaria case numbers.[58, 59] Generalized indoor residual spraying and case management since 2003 on Bioko Island (Equatorial Guinea) resulted in reduced *P. falciparum* infections.[60]

Problems of using pesticides such as DDT continue to exist in many countries.[61] Non-chemical control programmes using environmental management and biological control have been promoted or tested in pilot projects. But sustained implementation is uncommon[62] and support insufficient. This report presents six case studies: a historical project; three pilot projects which use non-pesticidal approaches to fight malaria effectively; and two National Control Programmes which stopped use of DDT and significantly reduced the incidence of malaria. The projects are characterized by improved or sustained malaria control; significant reduction in pesticides; cost-effective interventions; reduced environmental and health impacts and data on the malaria control methods; and, where available, the figures on development of malaria incidences (Figure 13, 15, Table 2).

Lessons from history

Malaya/Zambia

Prior to the 1940s – largely before DDT and other pesticides became widely available – a number of large scale projects were implemented which effectively reduced malaria. These projects focused on the reduction or elimination of mosquito breeding habitats (Figure 9). Malcolm Watson (1873 – 1955), a malariologist, was one of the pioneers who implemented environmental modification measures in rural and urban areas. He carried out detailed entomological surveys and examined the spatial distribution of malaria.

After identifying the principal breeding sites responsible for malaria transmission he applied selective larval control, which since then has been called »species sanitation«. This concept was first elaborated by Watson in western Malaya in the early decade of the 20th century. There, he dramatically reduced the incidence of malarial infections by implementing engineering approaches such as draining swamps and clearing vegetation.[63]

One prominent example of a historical malaria control strategy which incorporated environmental management as the central feature is a programme implemen-

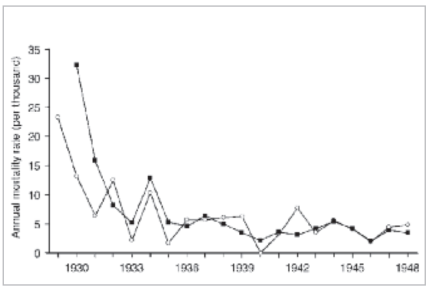
(Figure 9) Workers practising »vector control« by digging a drainage ditch (southern United States, 1920s). Source: CDC ted between 1929 and 1949 in former Northern Rhodesia, present-day Zambia. During the English colonial period four copper mining companies were operating in the country. In mid 1927 copper mining commenced at the Roan Antelope near Kitwe. It was difficult to attract labours because workers were afraid of dying if they were to stay permanently. The area was known to be hyper endemic for malaria and malaria was probably the leading cause of death. *P. falciparum* was the predominant species. *A. gambiae* and *A. funestus* were the predominant malaria vectors. *A. gambiae* was found in unshaded pools close to the river and open water tanks and wells. *A. funestus* prefers shaded banks, flooded areas and swamps.

The mine funded a malaria control and general sanitation programme, devised by the Ross Institute for Tropical Diseases in London. Malcolm Watson was in charge of malaria control at the institute. Between 1929 and 1949 the programme applied a multiplicity of interventions, most of which were centred on environmental management (clearing vegetation, modifying river boundaries, draining swamps, oiling and house screening). Many breeding sites were identified along the nearby Luanshya River, and its bank was modified and vegetation cleared. Shortly after the interventions were put in place, people became confident that the dangers of the river had been addressed and moved to the area, taking up work in the company. Housing conditions were improved and houses were screened. Water supply and sanitation facilities were also improved and a hospital was established. For some of the employees, mosquito nets and quinine administration was provided for prevention and cure of malaria.

The programme was well organized and rigorously implemented by the mining authority. Surveillance and monitoring allowed for a flexible approach. Malaria incidence rates and adult mosquito densities were monitored from the outset. The local community was mobilized, motivated and supervised to carry out the control measures.

During the first year of record-keeping the malaria incidence rate among the company employees reached 514 per thousand. It was halved after the first year of intervention and again halved one year later, remaining relatively stable after 1935. Overall mortality rates decreased dramatically, probably due to the reduction of malaria (Figure 10). The programme was implemented for 20 years and DDT was only utilised in the last five as an additional intervention strategy. Even though the interventions required a high initial capital investment they were remarkably cost-effective, and allowed unprecedented economic development.[64]

The environmental management strategies proved to be sustainable over the long-term enabling development of the Zambian copper belt by effectively controlling malaria. The project required significant input of labour. The approach was initiated under colonial rule, using a top-down, authoritarian approach with an initial capital investment of over US$1 million. Politically this approach is no longer acceptable and strategies favour community-based approaches supported by governments and/or non-governmental organisations.[65] Nevertheless the experience demonstrates that environmental management is cost-effective and can underpin economic development in a malaria-prone area.[22]



(Figure 10) Annual mortality rates (per thousand) due to diseases among Europeans (white dots) and Africans (black dots) living and working at the Roan Antelope copper mine.

Source: Watson (1953), extracted from Utzinger (2001)[64]

Environmentally friendly malaria control in Malindi and Nyabondo

Kenya

Kenya is among the five African countries where over half of the malaria cases occur. The majority of cases are caused by the parasite *P. falciparum*.[1] Geographically, 70 percent of the country is prone to epidemics; 20 million people are at constant risk of malaria and 26,000 children die every year. The National Malaria Strategy recommends ITNs as the major focus of malaria control and their use, together with coverage of both ITN and effective ACT therapy has been expanding. The National Malaria Control Programme distributed 7.1 million ITNs in 2006, of which 6.3 million were LLINs, and provided five million courses of ACT in 2006. As a result, there are indications that malaria morbidity and mortality is on a decline.[66] While the Division of Malaria Control does not carry out alternative control strategies, it recommends the use of larvicides, environmental management, zooprophylaxis, aerial space spraying and using coils, screens and repellents. During epidemics, indoor residual spraying is generally conducted, commonly using the insecticide lambda-cyhalothrin.[67, 68]

There are concerns about the use of pesticides in East Africa. In addition to potential harmful effects on humans and the environment, they can adversely affect the economy. Between 1997 and 2000 Europe imposed a ban on imports of fish products from the region around Lake Victoria due to elevated insecticide residues in East African products. This led to a proposal in early 2003 by the Minister of Environment and Natural Resources to ban the use of DDT. However malaria control still mainly relies on pesticides.[68]

To demonstrate how malaria can be controlled in different settings in Kenya in a more ecological and cost-effective way two pilot projects were initiated in 2004 and 2005 by the Swiss foundation Biovision in urban Malindi and rural Nyabondo. Scientific assistance comes from two local research institutions, ICIPE and the Kenyan Medical Research Institute (KEMRI), and local civil society organisations support the initiative. The project areas offer malaria mosquitoes numerous man-made breeding sites. To inform about the danger presented by stagnant water pools, local people are trained to become »Mosquito-Scouts«. Public awareness campaigns provide malaria information, »Mosquito days« are initiated to activate the local community for environmental management (through, for example, draining pools and canals, filling in pools of stagnant water) and personal protection is encouraged (Figure 11). Malaria awareness is incorporated into education in schools. Biological agents like *Bacillus thuringiensis israelensis* and neem are used to kill mosquitoes in their larval stage. LLINs have been distributed to improve personal protection. Monitoring and evaluation is essential, and the results are assessed to adapt malaria interventions to the local situation.[69, 70, 71]

The interventions resulted in larval and mosquito reductions and reduced malaria cases among children. From Malindi it is reported that malaria cases have halved from 10,000 at the beginning of the project (2005) to 5,000 in 2008.[72]

(Figure 11) ITNs for personal protection and clearing blocked drainages (water management) in Kenya. Source: Mbogo (2009)

Sri Lanka Farmer Field Schools – A case study of integrated pest and vector management

Farmer Field Schools (FFS) are an effective practical, field based learning strategy which work with farmers to transform agricultural practices by reducing dependence on pesticides and implement integrated pest management (IPM). IPM can improve yield and profits. Similarly, integrated vector management (IVM) strategies can help communities to tackle vector-borne diseases while reducing dependence on pesticide interventions. IVM and IPM strategies can be integrated into the FFS learning experience, particularly in areas where malaria (or other vector-borne diseases) is rife.

Sri Lanka is one of the Asian countries most affected by mosquito-borne diseases, with two species of malaria parasites, *P. vivax* and *P. falciparum*, being prevalent. The main mosquito vector is *A. culicifacies*. Agricultural practices pose several public health risks, especially in rice growing regions, because paddy fields and irrigation systems facilitate mosquito breeding. Research has identified the association between the development of irrigated rice lands and malaria epidemics.[73]

Malaria control activities are mainly based on chemical and pharmaceutical interventions in Sri Lanka. Early detection and prompt treatment is the mainstay of parasite control with support from the health infrastructure. Indoor residual spraying with malathion has been the major vector control measure, used in conjunction with insecticide-treated nets for personal protection and community awareness building through health education. But interest in developing non-pesticidal approaches has been growing especially as mosquitoes have developed resistance to DDT and malathion.[74]

FFS training was established in Sri Lanka 1995, providing practical field-based sessions with groups of rice farmers (Figure 12). A community-based pilot project, funded by the Food and Agriculture Organisation of the UN (FAO), UNEP and WHO, combining integrated pest and vector management began in 2002. The aim was to reduce the use of, and dependence on, pesticides not only in paddy cultivation but also for disease vector control. Farmers were both motivated and introduced strategies to reduce mosquito-borne diseases through environmentally sound methods that required no cost outlay. No monetary incentives were given to participants to attend the programme.

By mid-2006, the project had held 67 FFS on integrated pest and vector management. Participants were voluntarily conducting ecosystem management activities in their paddy fields including: levelling land to reduce the number of puddles; cleaning and water management of irrigation systems to make the current faster to avoid mosquito breeding; draining fields to prevent mosquito larvae reaching the adult stage; clearing coconut shells and containers; covering water containers at regular time intervals; and minimising pesticide use to conserve natural enemies of pests and mosquito vectors. In addition, participants eliminated breeding sites, applied oil, salt or fish to wells and water storage tanks and improved environmental sanitation in the residential areas.[75, 76, 77, 78]

The field school generated visible enthusiasm and self-confidence among farmers. The Department of Agriculture has reported both increased productivity and lower use of pesticides in the test areas. Lower mosquito larvae densities have been reported due to higher predator densities. Adult *Anopheles* density was significantly suppressed in some areas. Attributable to the project was also an increase of 60 percent in the use of bednets due to greater awareness about personal protection.[79]

The pilot project successfully achieved active participation of the community for the purpose of pest and vector management. The significant reduction of the vector species has shown that sound ecosystem management led by residents in a rice ecosystem has the potential to interrupt malaria transmission. For effective malaria control the ecosystem management should be accompanied by efficacious case treatment for pathogen control and by increasing knowledge through community education that encourages behaviour change to reduce human-vector contact.[73]

(Figure 12) Farmer presenting their results of field observations and agro-ecosystem analysis during weekly Farmer Field School sessions, Kendewa village, Anuradhapura District, Sri Lanka (2002).
Photo: van den Berg

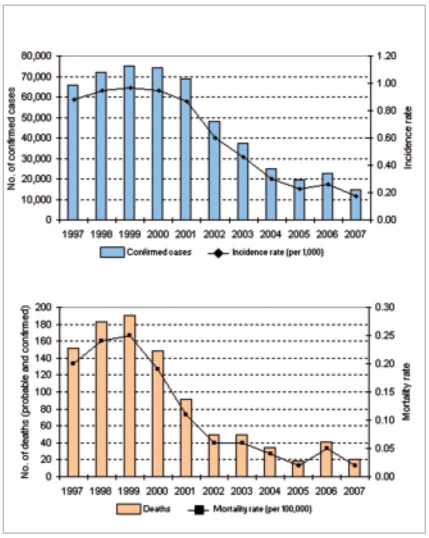
Vietnam A holistic National Malaria Control Programme

In 1991, Vietnam experienced a devastating malaria epidemic causing over one million malaria cases and almost five thousand deaths. Due to a general economic decline, investment for malaria control had fallen dramatically. Post-war population movements and shortages in drugs and insecticides contributed to the resurgence of malaria[80] and the shortages had not been compensated by other methods and approaches. In the same year, the government launched the National Malaria Control Programme. Since then funds to tackle malaria have increased from both domestic and external sources. DDT-spraying was abandoned and insecticide-treated nets became the key intervention. IRS became more targeted using pyrethroids. Mefloquine and later Artemisinin-based drugs replaced the chloroquine, quinine and sulfadoxin/pyrimethamin treatments to which parasites had become resistant. Today, commune and village health workers, motivated by government incentives, detect and treat 65 percent of all malaria cases. By 2006, the number of reported malaria cases was less than 100,000 – a spectacular decrease compared to the 1991 Figures (Figure 13).[81]

The key factors for the success of malaria control were a holistic approach based on extensive communication campaigns, public education about malaria, and promoting prevention strategies. The strategy established active leadership at all levels of government, mobilised and trained communities in malarial areas, provided technical support and ensured sufficient funding. Drug resistance has been monitored. Epidemiological surveillance has been strengthened through mobile teams. As a result, the interventions became more targeted with decision-making based on data gathered. The result was a dramatic decrease of the malaria burden in Vietnam.[82, 80]

Continued vigilance is essential as malaria remains prevalent in some places, usually rural, remote, forested and hilly areas. About half of all malaria cases occur in the central highlands and regular forest activity appears to be the strongest risk factor for malaria infection. The main vector in these areas is *A. dirus sensu strictu* which is highly anthrophilic, exophagic, exophilic and has early (day-time) biting habits which limits the impact of IRS and ITN interventions.[83] Malaria in these areas particularly affects migrant workers who seasonally migrate from non-endemic provinces and endemic areas. This could result in the spread of malaria to areas where transmission has virtually stopped.[84]

Even though the National Programme proved successful in some regions, the malaria problem in the Central Highlands and the mountainous districts of the Central coast provinces remains an extremely complex task. It is not only important to protect people in the forests but also to address poverty-related risk factors as low levels of education and poor housing conditions. A study in one province on the southern coast of Vietnam showed that a significant trend in decreasing the malaria burden was being brought about by setting up a case detection system based on village health workers trained to use rapid diagnostic tests and to administer the treatment.[83, 84, 85]



(Figure 13) Malaria morbidity and mortality in Vietnam, 1997 – 2007. Source: WHO (2009)

Pioneers of a sustainable strategy

Mexico

The Mexican model provides a unique example of an ecosystem approach to fighting malaria. Adoption of environmental management practices and improvement of personal hygiene, in combination with effective treatment of malaria cases, led to dramatic reductions in malaria transmission and discontinued use of DDT.

Malaria has been a long-standing public health problem in Mexico. Today, 99 percent of the cases correspond to *P. vivax*, with only a small number of cases of *P. falciparum* in some localities. The main vectors are *A. pseudopunctipennis* and *A. albimanus*.[86, 87]

In 1959 the first guidelines for eradicating malaria were implemented and DDT underpinned the strategy. Since the 1970's the use of DDT in agriculture declined due to environmental concerns and in 1987 DDT was exclusively restricted to public health programmes. The activities undertaken were able to combat the transmission of malaria cases to a considerable degree, but in 1998 a *P. vivax* outbreak along the Pacific Ocean coast in Oaxaca caused 18,000 cases of malaria. As a consequence the National Malaria Control Programme initiated a concerted effort to study the causes of the malaria outbreaks. The development of new strategies was encouraged by the North American Regional Action Plan to reduce human and environmental exposure to DDT, under which Canada, Mexico and the US agreed to phase-out DDT from their shared environment. In 1997, the goal set in Mexico was for an 80 per cent reduction in the use of DDT by 2002.[88]

Some researchers identified certain areas of high malaria risk by using a geographic information system which observed focal points of malaria transmission. In Oaxaca, 50 percent of the positive malaria cases were concentrated in less than five percent of the malarious communities. Within a community, malaria generally reoccurred in those families with poorer hygiene and housing conditions.[86, 87, 89]

Between January and June 1999 in Oaxaca those living in localities with the highest level of transmission received a three-month intensive course of treatment with chloroquine and primaquine to eliminate the parasite (focalised treatment). At the same time permethrin was applied in homes for three consecutive nights to rapidly diminish the density of mosquito vectors and parasites. With regard to malaria infections being symptomatic or asymptomatic, and the problem of relapses over the next three years, all individuals living in households where malaria had been detected received treatments to prevent its reoccurrence. Household spraying was carried out simultaneously. To reduce and eliminate the mosquito breeding sites communities were involved in environmental management measures, such as a monthly cleanup of filamentous green algae and trash from ri-

(Figure 14) Environmental management and house improvement for personal protection in Oaxaca, Mexico. Source: Méndez-Galván (2008)

Country	latest annual report	Percent change
Argentina	2004	- 74%
Belize	2006	- 43%
Bolivia	2006	- 40%
Brazil	2006	- 11%
Colombia	2006	- 9%
Costa Rica	2006	+ 55%
Dominican Republic	2005	+ 211%
Ecuador	2006	- 93%
El Salvador	2006	- 93%
French Guiana	2006	+ 10%
Guatemala	2006	- 42%
Guyana	2006	- 12%
Haiti	2005	+ 29%
Honduras	2006	- 67%
Mexico	2006	- 67%
Nicaragua	2006	- 88%
Panama	2006	+ 61%
Paraguay	2005	- 95%
Peru	2006	- 5%
Suriname	2006	- 70%
Venezuela	2006	+ 25%

(Table 2) Percent change in number of malaria cases reported by country (Compared to baseline 2000 data). Source: PAHO/WHO (2007)

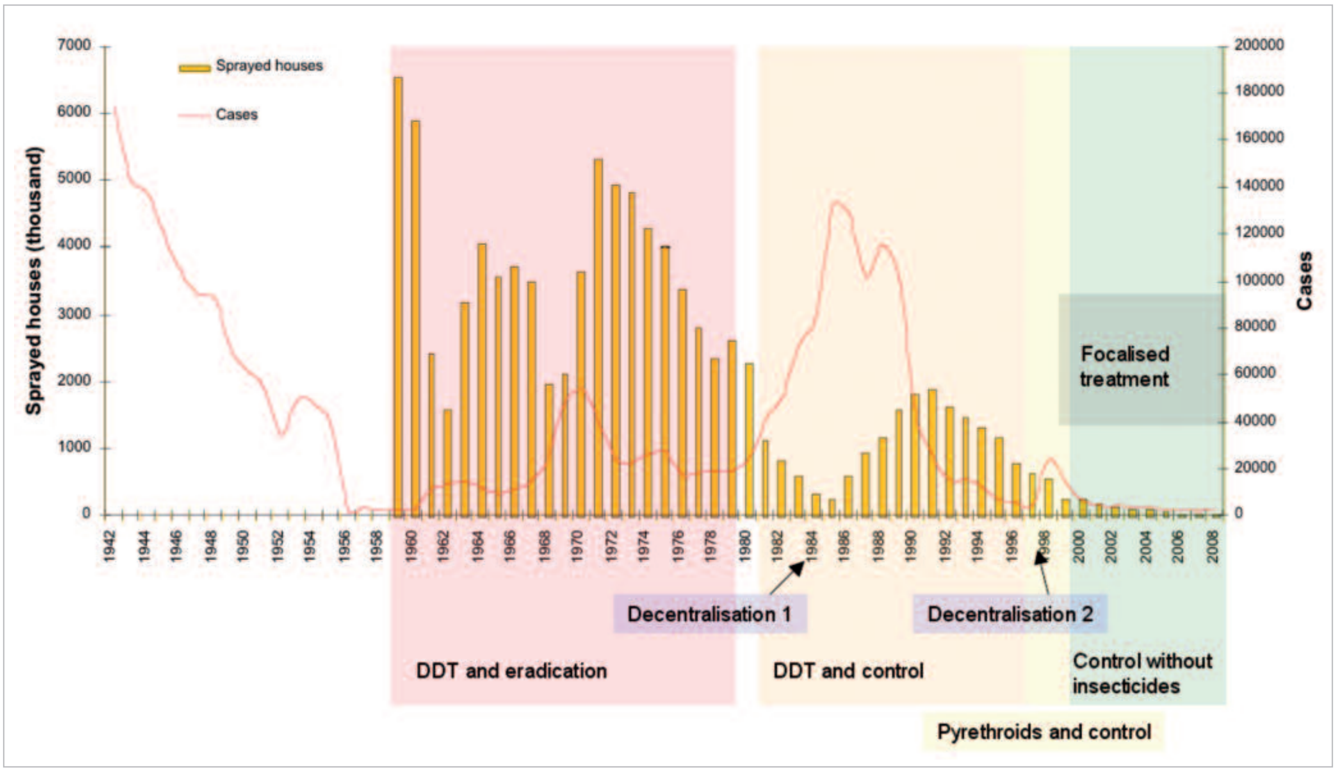
vers and streams. Since human and animal faeces attract mosquitoes, and vegetation offers them shelter, the family hygiene and housing conditions were improved: Walls were painted with an insecticidal paint, dirt floors were covered with cement, space was set aside for domestic animals, ventilation was improved, vegetation around homes was pruned and additionally trash was disposed correctly (Figure 14).[87, 89]

Over a three year period in Oaxaca the environmental management measures resulted in a 70 percent decrease in larval densities and an 80 percent reduction in adult mosquitoes. The number of malaria cases fell from 17,855 in 1998 to only 289 cases in 2001.[87]

The strategy was extended to the entire country between 2000 and 2002. Systematic insecticide application was suspended and spraying was carried out only during outbreaks. DDT was eliminated for malaria control in Mexico in 2000 – two years ahead of schedule and alternative pesticides (primarily deltamethrin) are now used only as a complementary element (Figure 15).[89, 90]

Following on from this success, the Pan American Health Organisation (PAHO) led the implementation of a »Regional Programme of Action and Demonstration of Sustainable Alternatives to DDT for Malaria Vector Control in Mexico and Central America« in partnership with UNEP and with funding from the Global Environment Facility (GEF). The PAHO pilot programme successfully demonstrated that pesticide-free techniques and management regimes could cut cases of malaria in many Latin American countries (Table 2). As a result, UNEP and WHO, in partnership with the GEF, announced the launch of ten new projects in 2009 under the global programme »Demonstrating and Scaling-up of sustainable Alternatives to DDT in Vector Management«. The project will involve some 40 countries in Africa, the Eastern Mediterranean and Central Asia.

(Figure 15) Malaria cases, house sprayings and strategies of control in Mexico. Source: Méndez-Galván (2008)



Conclusion

Malaria is a major global health problem. The tools and strategies currently employed to control malaria are substantially based on the use of chemicals, including highly hazardous pesticides.

Historically, environmental management effectively reduced malaria, and models suggest that dramatic reductions in malaria transmission are possible with environmental management.[94] Anti-malarial programmes in the US, Europe, the Middle East and some other previously endemic locations had largely eliminated malaria even before the use of chemical pesticides.[91] The successful strategies relied primarily on environmental management interventions to reduce vector breeding habitats, as well as advances in socioeconomic development, health care services and education.

Following the discovery of the insecticidal properties of DDT in the 1940s, the WHO endorsed the Global Malaria Eradication Programme (1955 – 1969) which primarily relied on chemical control: indoor residual spraying with DDT for vector control, backed up with pharmaceutical treatments. But eradication failed. When applied in India, this two pronged approach reduced malaria cases from an estimated 75 million in 1947 to just 49,151 cases in 1961. Nevertheless, financial, administrative and technical problems (such as DDT resistance) resulted in the resurgence of malaria and cases increased to 3,035,588 in 2006.[92] Today, malaria remains a major public health problem in poorer tropical regions and there is a correlation between the presence of malaria and poverty. Malaria control remains heavily dependent on chemical pesticides, particularly indoor residual spraying and insecticide-treated nets.

Growing concerns about impacts on the environment and human health calls for reducing reliance on insecticides for vector management, as reflected by the World Health Assembly and international conventions. The WHO recommends IVM, described as »a rational decision-making process for the optimal use of resources« for vector control to improve its cost-effectiveness, ecological soundness and sustainability.[93] On the other hand, the WHO promoted the use of DDT for IRS in 2006, so that a growing number of governments in Africa are opting for DDT use for malaria vector control. The Roll Back Malaria programme calls for scaling-up of ITNs and IRS, and this strategy, together with ACT treatment, appear to have cut the malaria burden significantly in some regions. But these interventions are vulnerable to vector resistance and to changes in the behaviour of *Anopheles* females. New low-risk insecticides, drugs and vaccines are not likely to become available in the near future, and consequently alternative approaches have to be strengthened.

A broad range of non-chemical malaria control approaches are known to be effective, including environmental management and biological control of the vector and non-pesticidal personal protection measures to reduce the human-vector contact.

The Zambian experience showed that multiple malaria control interventions, which relied strongly on environmental management strategies, could be successful. The pilot projects in rural and urban sites in Kenya and in Sri Lanka demonstrated

(Box 5) **Key points of success**

- Combination of multiple interventions adapted to local conditions
- Community participation
- Awareness raising
- Surveillance
- Decentralisation
- Local capacity building
- Intersectoral collaboration
- Improvement of public health system
- Income generation
- Involvement of civil society organisations
- Support by local research
- Regional cooperation

success with bioenvironmental malaria control. The projects successfully motivated local people to carry out control interventions and raised awareness through educational programmes. Vector density was reduced, potentially interrupting malaria transmission and simultaneously producing many collateral benefits, e.g. Sri Lanka, the programme raised agricultural productivity. In Kenya, the cooperation between a local research institute, local civil society organisations and the community enabled the implementation of environmentally friendly and cost-effective methods. Programmes in Vietnam and Mexico demonstrated that it is possible to phase out dependence on DDT, reduce reliance on pesticides and bring down malaria rates.

There are several important aspects to these success stories (Box 5). A detailed analysis of the local situation, supported by scientific research, could pinpoint localities where malaria is concentrated and thus enable treatment with efficient drugs and targeted IRS interventions to be focused on those most at risk. Through extensive communication campaigns and educational programmes, people are motivated to adopt personal protection measures. In Mexico, a combination of decentralisation, building local capacity and supporting surveillance, mobilises communities to tailor multiple interventions to the local conditions. Combinations of interventions adapted to the local situation are a key to sustaining malaria control efforts and enabling the effective application of non-pesticidal interventions.

Most poor countries lack the financial and technical capacity in their health systems to plan and implement programmes effectively and there is insufficient awareness of successful environmental management strategies in development agencies and the agricultural sector. Non-pesticidal interventions require substantial information about vector ecology and distribution of habitats, and must be designed with close attention to the local ecological, socioeconomic, political and cultural setting. Programmes require assistance with innovative research, the means to support the participation of communities and other sectors, a system of monitoring ways, the improvement of the public health system to ensure drug availability, and structures for regional collaboration.

Current research focuses primarily on chemical tools such as new pesticides and medical approaches such as new vaccines, and there is need to broaden the scope to encompass lessons from the successful and innovative alternatives documented in this paper. There is need for a detailed economic analysis of programmes to combat malaria so that the costs and benefits of alternative approaches may be compared.

New programmes need to set out strategies for involving local communities, relevant sectors, research institutions and civil society organisations to share information and to implement cost-effective and ecologically sound interventions, adapted to local conditions, thereby improving the living conditions and enabling sustainable development.

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15 'Very bioaccumulative' according to REACH criteria as listed by FOOTPRINT (BCF >5000)
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List of abbreviations

A.	*Anopheles*
ACT	Artemisinin-based Combination Therapy
AIDS	Acquired Immune Deficiency Syndrome
Bti	*Bacillus thuringiensis israelensis*
Bs	*Bacillus sphaericus*
CIA	Central Intelligence Agency
CDC	Centers for Disease Control and Prevention
DEET	N,N-diethyl-3-methylbenzamide
DDT	Dichlorodiethyltrichloroethane
EPA	Environmental Protection Agency
EU	European Union
FAO	Food and Agriculture Organisation of the United Nations
FFS	Farmer Field School
GEF	Global Environment Facility
HIV	Human Immunodeficiency Virus
IARC	International Agency for Research on Cancer
ICIPE	International Centre of Insect Physiology and Ecology
IPM	Integrated Pest Management
IRS	Indoor Residual Spraying
ITN	Insecticide-Treated Net
IVM	Integrated Vector Management
KEMRI	Kenyan Medical Research Institute
LD	Lethal Dose
LLIN	Long Lasting Insecticide-treated Net
PAHO	Pan American Health Organisation
P.	*Plasmodium*
PIC	Prior Informed Consent
POP	Persistent Organic Pollutant
REACH	Registration, Evaluation, Authorisation and restriction of Chemicals
UNEP	United Nations Environment Programme
UNICEF	United Nations International Children’s Fund
WHO	World Health Organisation
US	United States

PAN Germany
Pestizid Aktions-Netzwerk e.V.

Nernstweg 32, 22765 Hamburg
Tel. +49 (0)40-3991910-0
E-mail: info@pan-germany.org
www.pan-germany.org

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