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1. Introduction

The worsening malaria situation in many parts of the world led the World Health Assembly, in resolution WHA42.30 (1989), to declare malaria control a global priority and to request the Director-General of WHO to make all possible efforts to mobilize appropriate human, scientific and financial resources to this end. As part of its response to these concerns, WHO convened a Ministerial Conference on Malaria in Amsterdam in October 1992, at which the governments of both endemic and non-endemic countries signed a World Declaration on the Control of Malaria, committing themselves to control the disease (*1*). They agreed to improve the use of existing resources, to make malaria control an essential component of health and national development, and to involve communities as partners in control. At the same time, the signatories endorsed a Global Malaria Control Strategy, developed as the result of a series of interregional meetings at which the issues relevant to specific regions had also been reviewed. In 1993, the World Health Assembly reaffirmed the gravity of the malaria situation and, in resolution WHA46.32, urged Member States, interested parties and WHO to strengthen malaria control efforts; it also endorsed the World Declaration, which promulgates the Global Malaria Control Strategy, emphasizing the need to develop sustainable control programmes adapted to local needs.

Since the Ministerial Conference in 1992, efforts have been made to translate the Global Malaria Control Strategy into action, and a WHO Study Group met in Geneva in February 1993 to provide guidance for implementation of the Strategy (*2*).

A subsequent WHO Study Group on Vector Control for Malaria and Other Mosquito-Borne Diseases met in Geneva from 16 to 24 November 1993, primarily to develop specific guidelines for the implementation of the vector control component of the Global Strategy. The meeting was opened on behalf of the Director-General by Dr P. de Raadt, Director of the Division of Control of Tropical Diseases. Dr de Raadt emphasized the importance of vector control, and the need for selectivity and cost-effective and sustainable implementation. He underlined that, for malaria, the role of vector control is to prevent infection and thereby reduce malaria morbidity and mortality.

2. Background

Malaria continues to be a major public health problem in most countries of the tropical world and its control is becoming increasingly difficult (Box 1).

There are considerable variations in malaria epidemiology even within a single country due to variations in geography, ecology and human

Box 1

Malaria: global status and trends

Of the total world population of about 5.4 billion people, 2200 million are exposed to malarial infections in some 90 countries or areas. The most recent estimates indicate that there may be 300-500 million clinical cases each year, with countries in tropical Africa accounting for more than 90% of these. Malaria is also the cause of an estimated 1.4-2.6 million deaths worldwide every year, with more than 90% in Africa alone. It is one of the most important causes of mortality and morbidity among infants and young children, and infection during pregnancy contributes, primarily in primiparae, to maternal mortality, as well as to neonatal mortality and low birth weight.

In areas of intense transmission (stable malaria) most of the adult population is protected from severe disease by some degree of acquired immunity, but children under five years of age and pregnant women are highly vulnerable. In areas of unstable malaria, there is less acquisition of protective immunity, and all age groups may be at risk of disease; epidemics occur periodically, often with serious consequences.

Malaria is becoming more difficult to manage because of the spread of resistance of the parasite to antimalarial drugs. This demands use of alternative drugs which are generally more expensive and more difficult to administer and often have adverse effects. These additional difficulties place a severe strain on health services and pose a serious threat of increased severity of the disease and likelihood of death, particularly in areas of multidrug resistance, such as Cambodia, Myanmar, Thailand and Viet Nam.

Urban and periurban malaria is now a substantial problem in certain areas of Asia and Africa. Increased population movement precipitated by various socioeconomic and political factors often culminates in malaria epidemics; these are accompanied by high death rates and affect all age groups in the community.

activities, and there is no single control tool or approach appropriate to all the diverse situations. The vector control methods available vary in efficacy, duration of impact, resource requirements and the potential for community participation; they must therefore be used selectively.

Experience has shown that a thorough understanding of the malaria problem and risk and knowledge of the vector, the human host and the environment are prerequisites for effective planning and targeting of vector control interventions, for example in high-risk populations and defined geographical areas. An analysis of this information permits critical comparisons between different interventions prior to use, allows an assessment of areas or groups that would benefit most from vector control and facilitates evaluation of the impact of an intervention on the vector population and the disease.

The importance of technical and managerial decision-making associated with the comparison and selection of interventions and evaluation of vector control should be recognized. For this reason, this report outlines the vector control options to be considered and the indicators that must be monitored for the purpose of planning and evaluation. It also assesses the implications of the Global Malaria Control Strategy for the management of malaria control programmes and for human resources and training requirements.

Planning, implementation and evaluation have different implications for different institutional structures. For practical purposes, countries that were never included in the global malaria eradication programme, most of which have had little or no experience in vector control, have been defined as Category I countries under the Global Malaria Control Strategy. Countries that were included in the programme, which often maintain large-scale vector control activities with many aspects inherited from the malaria eradication era, have been classified as Category II countries. This dichotomy signifies that different approaches are needed for implementing the Strategy in the two categories of countries in the short and medium term.

Vector control is an essential component of malaria control programmes. However, its value and relevance have not been clearly recognized and its effectiveness has declined in recent years for several reasons. These include poor use of available alternative control tools, reduced effectiveness or inappropriate use of insecticides, lack of an epidemiological basis for interventions, inadequate resources including a shortage of trained personnel, inappropriate infrastructure and poor management. The problems of malaria control are aggravated by changing environmental conditions in areas in which exploitation of natural resources and development activities are taking place. Massive population movements (forced and voluntary) to endemic areas and increasing parasite resistance to drugs add to the difficulties.

The future success of vector control as part of the Global Malaria Control Strategy thus depends upon a systematic review of the available vector control options and their selective use. The varied and changing epidemiological and disease conditions should be taken into account, as well as differences in the infrastructure and resource base from which the different malaria control programmes operate. The use of insecticides may continue to be an important component of vector control, but should take account of vector and human behaviour, insecticide resistance and safety, cost-effectiveness and environmental impact. Other available tools such as environmental management should also be considered and selectively deployed.

3. Goals and objectives

3.1 Goal and technical elements of the Global Malaria Control Strategy

The goal of the Global Malaria Control Strategy is to prevent mortality and reduce morbidity and social and economic losses, through the progressive improvement and strengthening of local and national malaria control capabilities (*1*).

The four basic technical elements of the Global Strategy are:

- to provide early diagnosis and prompt treatment;
- to plan and implement selective and sustainable preventive measures, including vector control;
- to detect early, contain or prevent epidemics;
- to strengthen local capacities in basic and applied research to permit and promote the regular assessment of a country's malaria situation, in particular the ecological, social and economic determinants of the disease.

Three of the above-mentioned elements of the Strategy involve vector control.

3.2 Objective of vector control

Within the Global Malaria Control Strategy, selective vector control is defined as the application of targeted, site-specific control activities that are cost-effective. The principal objective of vector control is the reduction of malaria morbidity and mortality by reducing the levels of transmission (*2*).

3.3 Objectives of the Study Group

The primary objective of the Study Group was to develop guidelines for planning, implementing and evaluating vector control interventions and their selective use for malaria prevention and control in the context of the Global Malaria Control Strategy.

Secondary objectives to support the primary objective included:

- review of the currently available methods of vector control and their potential for effective application in different epidemiological and operational situations;
- review of the role of the entomological component of national malaria control programmes in accordance with the Global Malaria Control Strategy;
- identification of the needs and priorities for development of local capacities, mainly human resources, in relation to vector control and entomological services;
- establishment of research priorities for vector control in the context of the Global Malaria Control Strategy;
- identification of the potential role of malaria control programmes in the control of other mosquito-borne diseases.

The resulting guidelines are intended to be used by the personnel of national malaria control programmes (programme managers, entomologists and other relevant staff), by others involved in the control of malaria and other mosquito-borne diseases, and by policy-makers and decision-makers. They should also be of interest to anyone else whose activities may have an impact on the malaria situation or on its control.

3.4 Use of DDT in vector control

As a result of recent publicity concerning the alleged carcinogenicity of DDT, there has been an upsurge of queries on WHO's position on the use of DDT for malaria control. Since many endemic countries rely on DDT for the control of both malaria and visceral leishmaniasis (kala-azar), the Study Group was asked, as a specific additional task, to review the current situation regarding the use of DDT in vector control. Its conclusions are presented in Annex 1.

4. Global status and trends in malaria and other mosquito-borne diseases

The mosquito-borne diseases – malaria, filariasis, dengue, yellow fever and Japanese encephalitis – contribute significantly to disease burden, death, poverty and social debility in tropical countries (Boxes 1-5). Of

Box 2

Lymphatic filariasis: global status and trends

Approximately 750 million people are at risk of lymphatic filariasis, mainly caused by *Wuchereria bancrofti*. Nearly 80 million people are infected and some 30 million of them experience the chronic disease. Of those with chronic infection, more than 1 million suffer from overt elephantiasis, the most disfiguring form of the disease.

The epidemiological situation is geographically very variable. For example, in the past 10 years effective control has greatly reduced the prevalence of *W. bancrofti* and *Brugia malayi* infections in China, which accounts for a marked decrease in the total number of infections reported from WHO's Western Pacific Region. But in the South-East Asia Region, India alone now reports 45 million people infected, a substantial increase over the 18 million estimated in 1983; this is mostly due to an overall increase in populations living in the endemic areas.

Little is known about the economic impact of lymphatic filariasis on communities. However, studies have indicated that, as a debilitating and disfiguring disease, it can have a considerable psychosocial impact and can cause significant loss of income as a result of decreased productivity due to both acute episodes of incapacitating disease and chronic disability.

Figure 1

Global distribution of indigenous malaria, as reported to WHO[a]

The designations employed and the presentation of material on this map do not imply the expression of any opinion whatsoever on the part of the World Health Organization concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. Dotted lines represent approximate border lines for which there may not yet be full agreement.

[a] Unshaded areas: no indigenous malaria reported to WHO or no information available. For a listing by country, see Annex 5.

Box 3

Dengue and dengue haemorrhagic fever: global status and trends

Dengue and dengue haemorrhagic fever are the most important arboviral diseases in terms of public health impact, and their incidence is rapidly increasing. In the countries affected, debilitating symptoms and death occur in people from all social strata, most frequently among the very young and the elderly. Most cases occur in densely populated urban areas; but the poor in both urban and rural areas are generally at greater risk because of inadequate basic health and sanitation services. The main vector in urban areas is *Aedes aegypti* and in suburban and rural areas it is *Ae. albopictus*. The global spread of *Ae. albopictus* is giving cause for concern.

Epidemics of dengue and dengue haemorrhagic fever threaten nearly two-fifths of the world's population, in 100 countries, accounting for millions of cases of disease and thousands of deaths each year. Dengue has recently caused extensive epidemics in non-immune populations in Africa, the Americas, Asia, the Pacific islands and certain countries of WHO's Eastern Mediterranean Region. Thirty-seven countries have experienced outbreaks of dengue haemorrhagic fever, and in many countries, outbreaks of dengue and dengue haemorrhagic fever are the leading cause of hospitalization of young children. Laboratories are often not equipped to diagnose dengue promptly and vector control programmes are insufficient to ensure transmission control. The capability to recognize outbreaks at local and national levels is frequently inadequate and therefore the disease is not contained and spreads rapidly. Loss of income as a result of the disease is also a major problem.

The World Health Assembly recently adopted a resolution (WHA46.31, 1993) for global commitment to the prevention and control of dengue and dengue haemorrhagic fever.

Box 4

Japanese encephalitis: global status and trends

Japanese encephalitis has been reported in 14 countries in three geographical regions: south Asia (e.g. India and Sri Lanka), south-east Asia (e.g. China and Indonesia) and the Pacific islands (e.g. Japan).

Though the number of cases reported in these countries decreased from about 150 000 in 1970 to about 45 000 in 1990, a corresponding reduction of deaths due to the disease was not reported. On the contrary, the number of deaths reported increased from 422 in 1970 to about 4300 in 1990; the highest number of deaths was reported from China. Neurological sequelae in survivors of the disease are often severe.

Increased rice cultivation made possible by new irrigation projects has led to increased breeding of vectors, mainly *Culex tritaeniorhynchus*. This, together with more widespread rearing of pigs (pigs are an amplifier host of the virus), has in the recent past caused many outbreaks of Japanese encephalitis. The disease tends to become endemic in these situations.

Box 5

Yellow fever: global status and trends

The number of cases of yellow fever reported to WHO from Africa increased in the mid-1980s (5104 cases in 1986, mostly from Nigeria), but decreased to 2561 cases in 1991 (when all the reported cases were from Nigeria).

In the Americas, five or six countries report, between them, a total of 50-250 cases annually.

these diseases, malaria (Fig. 1) is by far the most important in terms of the number of individuals it affects and of deaths it causes. Various demographic, ecological, environmental and sociological trends are contributing to increases in the prevalence and incidence of malaria and of other mosquito-borne diseases in certain areas.

Although the Study Group focused on malaria in the context of implementing the vector control component of the Global Malaria Control Strategy, many of the issues addressed during the meeting are also relevant to a large extent to the prevention and control of other mosquito-borne diseases.

5. Malaria status and experiences, priorities and trends in vector control in the WHO regions

There is wide variation in malaria status and experiences in vector control between the WHO regions and between countries. Some countries have never carried out organized vector control, while others rely heavily on insecticide use or have progressed considerably towards implementing selective vector control as defined within the Global Malaria Control Strategy. Thus the immediate priorities and approaches for implementing the vector control component of the strategy will vary widely, including within and between countries in Categories I and II.

5.1 African Region

Malaria is a major cause of disease and death in the countries of the African Region. About 93% of the 550 million people living in Africa are at risk of malaria. Of the estimated annual global total of 300-500 million clinical cases of malaria and 1.4-2.6 million deaths, over 90% are reported from Africa.

About 75% of the people in Africa live in areas of highly endemic stable transmission. Another 18% live in epidemic-prone areas where malaria transmission is seasonal and unstable and where all age groups are vulnerable to infection and disease.

Throughout the African continent, early diagnosis and prompt treatment form the primary strategy for reducing malaria mortality and morbidity. Organized vector control activities are carried out in very few of the countries with endemic and stable malaria. However, if carefully chosen, preventive activities can have some impact.

In countries that are highly prone to epidemics, such as Botswana, Burundi, Ethiopia, Madagascar, Namibia, Swaziland, the United Republic of Tanzania and Zimbabwe, disease management is complemented by indoor residual spraying and antilarval measures. Vector control interventions in some countries, e.g. the United Republic of Tanzania, are undertaken through a programme supported by bilateral assistance, and include: indoor residual spraying and space spraying, use of treated bednets, antilarval measures, source reduction to eliminate breeding sites, and use of polystyrene beads to cover breeding sites in urban and periurban areas. Plans are under way to replace indoor residual spraying by use of treated bednets. In the Ruzizi valley of Burundi, indoor residual spraying has been carried out periodically since 1985 before the onset of the main transmission period, and has reduced the proportion of infections with high-density parasitaemia. Selective insecticide use, which has reduced selection pressure, has presumably helped to maintain susceptibility to malathion.

In the countries and territories that are now free from malaria transmission, e.g. Cape Verde, Mauritius, Réunion and parts of South Africa, the primary objective is to prevent its reintroduction. In Réunion, for example, malaria was eradicated in 1979, but since numerous imported cases are detected every year, vector control measures are undertaken, involving larviciding and focal residual spraying of houses in which imported cases are found. Disinsection of aircraft and ships is carried out according to the International Health Regulations.

A major cause for concern in many countries of the African Region is the scarcity of trained entomologists and epidemiologists in public health services. This lack will hinder the planning, implementation and evaluation of vector control in keeping with the requirements of the Global Malaria Control Strategy. Lack of resources to purchase supplies and equipment is also a continuing constraint.

5.2 Region of the Americas

In the Americas, 21 countries and territories now report a total of more than 1 million cases of malaria per year. This is an increase from the 270 000 cases reported in 1974, and the 600 000 in 1980. The annual malaria mortality rate is approximately 156 per 100 000 inhabitants. More than 280 million people are at risk, i.e. 40% of the population in malarious or potentially malarious areas.

There was a decline in reported cases in the Americas from 438.8 per 100 000 population in 1991 to 409.5 per 100 000 in 1992. Of the cases reported in 1992, 51.3% were from Brazil and 27.4% from the Andean countries (Bolivia, Colombia, Ecuador, Peru and Venezuela). The annual parasite index in malarious areas was greatest in French Guiana, Guyana and Suriname (38.5 per 1000) followed by Brazil (9.5 per 1000) and Central America (8.5 per 1000).

Historically the ministries of health have been responsible for all aspects of malaria control in the countries of the Region. Operational strategies including vector control activities are planned and directed at the national level with coordinators at the state level who are responsible for both routine and emergency operations.

Indoor residual spraying is usually the main vector control approach. Though some countries have increased spraying coverage and others have decreased it, the number of houses reported sprayed remained unchanged from 1987 to 1992. In 1992, DDT accounted for 73% by weight of the insecticide used for indoor residual spraying. The percentages of other insecticides used were: malathion 5%, fenitrothion 8%, propoxur 0.4%, and others 13%.

Brazil has recently placed emphasis on environmental management to control the breeding sites of anopheline mosquitos in the periurban areas of the Amazon basin.

Vector resistance to DDT coupled with the recent attempts to decentralize health systems has prompted the implementation of new strategies for vector control. For example, along the Pacific coast of Colombia, *Anopheles neivai* has been controlled in one village by removing its larval habitat (bromeliads) from surrounding trees. The other vector in the coastal area, *An. albimanus,* has been effectively controlled by draining nearby breeding sites and applying *Bacillus thuringiensis* serotype H-14 to sites that could not be drained. In El Salvador, a major component of the vector control programme has been the environmental management of vector breeding sites and malaria incidence has decreased considerably since the early 1980s. In Venezuela where *An. aquasalis* is the principal vector, good progress in malaria control has been achieved through a combination of space spraying and application of *B. thuringiensis* H-14. This programme was implemented at the state level and resulted in a decrease of over 90% in malaria incidence in less than a year.

Malaria stratification (see section 6.4.2), early diagnosis and treatment, and social participation at the local level are the main contributory factors to the success of the above-mentioned programmes. Cost-effectiveness analysis is being planned.

In recognition of the importance of human resource development in vector biology and control, the Region of the Americas promotes and supports:

- the training of professional public health entomologists at central and local levels;
- the introduction of certain important aspects of vector control into education programmes for health personnel;
- the formation of a core group of professionals with the ability to provide technical support for local programmes, including planning and monitoring;
- the provision of a favourable career structure for public health entomologists.

5.3 Eastern Mediterranean Region

Malaria is the most important vector-borne disease in the Eastern Mediterranean Region and it is endemic in 14 out of the 22 countries. The number of cases is currently increasing in some countries. Imported cases have been identified in countries or areas where no indigenous cases have been reported recently, indicating a potential threat of reintroduction of malaria. Out of a total population of approximately 400 million in the Region, about 240 million people are at risk; of those at risk about 197 million were living in areas of malaria control activities in 1992. There are an estimated 10 million cases of malaria and 100 000 deaths per year.

Of the factors contributing to the increasing number of cases of malaria, those of relevance to vector control include: the scarcity of expertise in vector biology and control; an increase in malariogenic potential caused by development projects (for water resources, agriculture and other purposes); mass population movement and temporary settlements such as refugee camps; vector resistance to insecticides; lack of community involvement; and the inability of the primary health care system to take responsibility for vector control activities.

The main objectives of the Regional vector control strategy are therefore:

- to ensure adequate human resources at all levels for the planning, implementation and evaluation of operations to control disease vectors and nuisance pests;
- to strengthen the vector control components of general health services and other institutions of Member States;
- to ensure that priority is given first to environmental management and then to biological methods of vector control, and that chemical insecticides are used only as a last resort;
- to ensure that the control of vectors and pests is given adequate consideration in natural resources development projects;
- to develop effective and safe vector and pest control programmes based on ecologically sound strategies and in accordance with the principles of sustainable development, and to promote integrated vector control;

- to ensure that community education and participation are emphasized in all vector control programmes and that the primary health care system is the main vehicle for the delivery of safe and sustainable vector control measures.

5.4 South-East Asia Region

The malaria situation in WHO's South-East Asia Region has remained static since 1983, with the incidence of malaria between 2.5 and 2.9 million cases annually, though the proportion of *Plasmodium falciparum* malaria increased from 36.8% in 1990 to 42.7% in 1991. Forest-related malaria represents 30–80% of the total cases, 50–90% of all *P. falciparum* malaria and a majority of infections with drug-resistant *P. falciparum.*

Factors considered to be impeding malaria control efforts in the countries of the Region include the resistance of *P. falciparum* to various antimalarial drugs, vector resistance to insecticides, changing vector behaviour, high efficiency of certain vectors, multiple-vector transmission, prolonged transmission seasons, and large-scale and uncontrolled population movements.

Of a total population of 1302 million in the Region, 88% live in malarious areas. During 1992, 18% of the people living in malarious areas were protected by indoor residual spraying and 7% by larviciding; only small numbers were covered by other vector control measures (e.g. biological control 0.5%, environmental management 0.01%, and use of insecticide-treated bednets 0.002%).

Indoor residual spraying has been one of the major vector control strategies used by the national malaria control programmes for many years, consuming 30–90% of the total malaria programme budget for each country. In spite of the high expenditure on indoor residual spraying, the desired reduction in malaria incidence has not been achieved.

The vector control strategies currently in use must therefore be critically reviewed and reoriented. In replanning control programmes the following approaches are being emphasized in the Region:

- undertaking stratification (see section 6.4.2) to facilitate planning of selective and cost-effective vector control strategies;
- establishing criteria for planning and setting priorities for vector control, aimed at reducing indoor residual spraying and increasing the use of other vector control measures as appropriate to local epidemiological characteristics and resource availability;
- implementing vector control activities through primary health care systems.

5.5 Western Pacific Region

In the countries of the Western Pacific Region a total population of about 150 million is at risk of malaria.

Selective vector control strategies are an integral part of malaria control programmes in all nine malarious countries of the Western Pacific Region. Two forms of vector control are being used: indoor residual spraying and pyrethroid-treated bednets.

Only three countries continue to carry out regular indoor spraying: Malaysia, the Philippines and Viet Nam. Of the three, Malaysia is the only country where spraying covers all malarious areas. In the Philippines and Viet Nam it is restricted to specific high-risk areas. Spraying was discontinued in the other six countries because of an inability to sustain effective spraying programmes. This was attributed to a combination of factors that included inadequacies in training and supervision of field staff, transport facilities, planning and management and lack of insecticides.

All nine malarious countries are in the process of introducing pyrethroid-treated bednets as their primary form of vector control. The speed of this change varies. China has covered an estimated 6% of the population at risk; it is thought that 63% of those at risk actually have access to bednets, but the extent of insecticide treatment is not clear, especially now that malaria incidence is declining. In the other eight countries, coverage estimates are: Solomon Islands 28%, Vanuatu 25%, Papua New Guinea 15%, Malaysia 12%, Viet Nam 8%, Cambodia about 5%, Lao People's Democratic Republic 2% and the Philippines less than 1% of the population at risk. Although the bednets appear to be well accepted and used in most areas, there are clearly some drawbacks:

- The bednets have not been accepted everywhere.
- The expected high level of community participation has not been reached in most situations. Most programmes have too few field staff for the proper management of large-scale operations.
- In areas where vectors are exophilic and exophagic, such as the South Pacific (*An. farauti*) and parts of Indochina (*An. dirus*), the effect of the bednets is limited.
- Many of the problems that limited the effectiveness of indoor residual spraying – poor management, weak health infrastructure, insecticide resistance, inadequate numbers of field staff and poor field supervision – are shared by the insecticide-treated bednet programmes or may become problems in the future.

There is therefore serious concern that malaria control through use of treated bednets may eventually become ineffective as a strategy.

Entomology services have been given a low priority within most malaria control programmes in the Region. There are very few qualified entomologists and many of those now attached to control programmes for malaria or other vector-borne diseases leave because of poor career prospects. There is an acute need to revive entomology services and to reorient them to meet the practical needs of control programmes.

6. Vector control in the context of the Global Malaria Control Strategy

6.1 Objective of vector control

As already indicated (section 3.2), within the Global Malaria Control Strategy, selective vector control is defined as the application of targeted site-specific control activities that are cost-effective. The principal objective of vector control is the reduction of malaria morbidity and mortality by reducing the levels of transmission (*2*).

6.2 Important considerations in planning and implementation

The Global Malaria Control Strategy calls on countries in which malaria is endemic to plan and implement selective and sustainable vector control aimed at disease prevention.

The following considerations are important in planning and implementing vector control (see also Annex 2).

- Malaria is focal and variable in nature.
- Environmental changes and uncontrolled population movements associated with development projects and exploitation of natural resources often exacerbate malaria transmission or its potential.
- The increasing problem of drug resistance makes minimizing transmission in the affected areas a high priority.
- The absence of broad-spectrum control methods demands the selective use of one or more vector control measures to reduce malaria transmission. Non-discriminatory reliance on a single approach or tool is strongly discouraged.
- Due attention should be paid to entomological risk factors (determined by vector biology, ecology and behaviour) and their relation to other epidemiological variables, in particular the human host and the parasite.
- Inappropriate use of insecticides, increasing vector resistance, and high operational costs jeopardize the sustainability of control programmes that rely heavily on insecticides.
- There are differences in the infrastructure and resource base from which the various malaria control programmes operate.

6.3 Selectivity and sustainability

Selectivity in vector control requires appropriate decisions on what control method(s) to use, and when and where to use them to maximize cost-effectiveness. The identification of situations in which vector control is not required is also important. The selection takes into consideration the magnitude of the malaria problem (preferably in quantitative terms), epidemiology, the levels of transmission and risks, priority groups or areas requiring protection, technical and operational realities, infrastructure and the resources and information available. The major vectors of malaria must be known, and their distribution and breeding, resting and feeding habits clarified and related to disease transmission.

Vector control measures may be considered for application:

- to deal with existing problems such as malaria outbreaks or epidemics and high rates of mortality and morbidity and to control transmission in areas with a drug resistance problem;
- to prevent epidemics or the reintroduction of malaria;
- to reduce environmental risk factors for transmission, which can have consequences both for disease prevention and, more generally, for health and development (for example through improvement of living conditions).

The role of the personnel of malaria control programmes in these different situations will vary.

Sustainability in vector control requires continuous political support and commitment to controlling malaria together with continuous resource support to maintain the programmes. A sustainable vector control programme also needs human resources with the necessary skills and knowledge to determine when and where action is needed and community acceptance of, and participation in, interventions. Appropriate methods and targets must be selected, and the available control tools should be suitable for long-term use. Sustainability implies that, when progress has been made in the control of malaria, the achievements are maintained. There must often be a change in behaviour and attitudes at all levels so that everyone understands, appreciates and is motivated towards carrying out the requirements of the vector control programme.

6.4 Planning and implementation

The immediate approaches to planning and implementing vector control will differ between countries, mainly between Category I and Category II countries. The ultimate goal, however, is the same everywhere. In most countries in Category I, a vector control programme needs to be established on the basis of available information related to the malaria situation, malaria risks and the vectors. This information should be continually updated. Category II countries need to (re)orient their vector control activities towards selective use of different control methods and reduced reliance on a single tool (e.g. insecticide use) that is unlikely to be sustainable in terms of impact or application possibilities.

The approaches and actions to be considered in planning and implementing vector control are described below in sections 6.4.1-6.4.3, and the salient actions are summarized in Annex 2.

6.4.1 *Information systems and management*

A timely response to changes in malaria transmission and the risk of disease depends on an information system which allows rapid collection, analysis and exchange of information for planning, implementing, monitoring and evaluating programmes.

Only the most pertinent information for decision-making and evaluation at various levels should be collected. Certain types of information and data are needed regularly and others only in special circumstances. Information may be collected from a variety of sources within and outside the health services. Therefore close collaboration between malaria control programmes, the general health services, and sectors that contribute inadvertently to the malaria problem or support control activities is critical. Speedy and efficient management of information allows rapid responses to disease prevention and control needs. Properly maintained computerized databases could facilitate this.

The planning and implementation of vector control require information in the four basic areas discussed below: the human host, the disease, the vector and the environment where transmission takes place. The information must be compiled and analysed by trained personnel (epidemiologists, entomologists and public health engineers) and presented in a convincing manner to the administrators and others involved in planning and implementation.

The human host

Information is needed on population structure and distribution, family size, occupations, patterns of population movement, the size and nature of ethnic minority groups and income levels. Much of this information should normally be available from census bureaux. Together with data on the vector and on disease distribution, it will allow the identification of special risk groups, their location and the type of vector control to be applied.

A knowledge of local human behaviour (e.g. sleeping habits) and the community attitude towards, and acceptance of, a particular control approach will help the planning process. For example, if nets are already widely used, the treatment of bednets with insecticide will supplement existing practice. If they are not traditionally used, then implementation of a programme based on bednets may be difficult without some encouragement and motivation, for example through health education.

The disease

Epidemiological data such as disease incidence by age, sex and occupation will provide information on the sections of the population at greatest risk, which people are serving as reservoirs of infection and where the infection may have been contracted. Information on the spatial and temporal distribution of the disease and on the parasite species, virulence and drug resistance status further serves to identify the areas and seasons that should receive priority for vector control activities.

The vector

In order to match control options to the local vector characteristics, information is needed on preferred breeding sites, rainfall patterns, extent of surface water (when larval control is considered), seasonal changes in vector densities, host preferences, whether mosquitos enter houses or bite outside, biting times and susceptibility to insecticides.

The environment

Information about the environment where transmission takes place, including the quality and type of housing, availability of piped and irrigation water and water-storage containers, and location of dams, is helpful in planning specific aspects of vector control.

6.4.2 *Stratification of malarious areas by eco-epidemiological criteria*

Malaria "stratification" is the first step towards planning malaria control. It involves the classification of malarious areas by major eco-epidemiological type, as determined from their more easily recognizable characteristics and other available information. Specific risks may be associated with each epidemiological type, so that for each type certain

Box 6

Stratification for planning vector control: Venezuela

In Venezuela, three malarious regions and their predominant vector species have been identified: the north-eastern coast where *An. aquasalis* predominates, the western piedmont (highland fringe) where *An. nuneztovari* is predominant and the southern lowland forest regions where *An. darlingi* is the predominant vector. *Anopheles aquasalis* and *An. nuneztovari* are more exophilic, exophagic and zoophilic than *An. darlingi. Plasmodium vivax* is responsible for 97% of the malaria in the north-eastern coastal and western piedmont regions, while in the southern lowland forests *P. falciparum* is responsible for 40–60% of the malaria. On the basis of this information, the Venezuelan malaria control programme has suspended all indoor house-spraying in the coastal area. In the piedmont area, the possibility of concurrent discontinuation of indoor house-spraying, institution of the use of impregnated materials, and improved and more rapid diagnosis and treatment of malaria is under discussion.

The anthropophilic behaviour of *An. darlingi* in the southern lowland forests implies that focal indoor residual spraying of houses is relevant where suitable housing exists. But in mining areas where housing is poor, organized cooperatives and government personnel use space-spraying as well as rapid diagnosis and treatment of malaria. In addition, the malaria control programme is currently assessing population movement patterns.

The characterization of malarious regions by ecological type, vector dynamics and human behaviour is essential for the appropriate control of malaria in Venezuela.

Box 7

Stratification for planning vector control: Malaysia

Malaysia has been divided into three epidemiological strata: malarious, malaria-prone and malaria-free. Malarious areas have been further divided on a smaller scale to permit identification of villages that are truly malarious as opposed to malaria-prone or malaria-free. Vector control measures, including either residual spraying or use of insecticide-treated nets, are then applied to whole villages or to groups of villages in malarious areas. Special risk groups such as people working on agricultural/development projects, aborigines and forest workers are also identified as targets for vector control activities. Active disease surveillance is maintained in malaria-prone areas, and when an outbreak is detected, focal vector control actions are instituted. In peninsular Malaysia and Sabah, focal vector control generally involves residual spraying, whereas Sarawak emphasizes treatment of existing bednets. Border areas in which drug resistance is a problem may need to be considered a special epidemiological stratum for the purposes of vector control.

control approaches may be more appropriate than others. Some of the major epidemiological types of malaria have been defined in the context of the Global Strategy (*1*). These can serve as a starting point for individual countries to define their local malaria situation and provide a basis for more detailed analysis (Boxes 6 & 7).

Continuous analysis of information concerning each of the major malarious areas or epidemiological situations is needed to establish the needs and priorities for vector control and to select the appropriate methods and timing for interventions. More detailed analysis may allow identification of smaller areas, individual villages, groups of houses or populations and appropriate times of year for more precise targeting of specific interventions. Much of the required information can be extracted from data already recorded through surveillance processes in many Category II countries or can be collected over time.

6.4.3 *Priority geographical areas and risk groups*

Priorities for vector control are related to the magnitude of the malaria problem and the associated risks. Areas that should generally receive high priority for vector control are those with malaria epidemics, a high risk of disease transmission, mortality and morbidity (in particular due to severe malaria), or a drug-resistance problem. In general, children, pregnant women, non-immune populations, people living in inadequate housing and houses close to important and permanent breeding sites should be given priority. The feasibility of implementing vector control in priority areas will depend on many factors, including the limitations of available control methods, specific vector, human and environmental characteristics and the available resources.

Priorities for vector control may vary over time. Thus information has to be analysed continuously to take into account any changes in vector habits, alterations in patterns of disease transmission, environmental changes and population movements.

7. Vector control options

The vector control options that are currently available are:

- indoor residual spraying
- use of personal protection measures
- biological control
- larviciding (including use of biocides)
- environmental management, including source (breeding site) reduction
- space-spraying (which has limited application; see Box 8).

Vector control measures should take advantage of the specific characteristics or survival requirements of the different vectors. Many of the methods target the period of larval development or make use of the resting and feeding habits of the adult mosquitos. The various control options are aimed at reducing or eliminating vector production, reducing adult vector populations, reducing the life span of adult females and preventing vector contact with humans.

7.1 Indoor residual spraying

Indoor residual spraying with DDT was the major reason for the success of malaria control in the 1950s and 1960s. Malaria was eradicated, or almost eradicated, from many parts of the world during this time. House-

Box 8

Space-spraying

Space-spraying with insecticides may sometimes be relevant in urban areas and where large numbers of people congregate outdoors at night. This method has been used against *Anopheles*, *Culex* and *Aedes* spp. mosquitos in various countries. The spraying operations must be timed to coincide with the peak activities of the vectors. The operational costs are extremely high and the residual effect is low. Therefore space-spraying should be undertaken only in exceptional circumstances, for example during epidemics in urban areas, as an emergency measure to immobilize infective mosquitos and contain transmission.

In South America, space-spraying has been used extensively against outdoor-resting *Anopheles* spp. and in the mining areas where housing is inadequate. The residual effect lasts only a few days and the overall cost-effectiveness has not yet been evaluated.

spraying remains a valuable tool in malaria control when applied in the right circumstances. Experience has also shown, however, 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.

7.1.1 *Conditions for use and effectiveness*

Indoor residual spraying may be considered an appropriate method for vector control when the following conditions are met:

- a high percentage of the structures in an operational area have adequate sprayable surfaces, and can be expected to be well sprayed;
- the majority of the vector population is endophilic, i.e. rests indoors;
- the vector is susceptible to the insecticide in use.

In these circumstances, indoor residual spraying can reduce the vector life span, vector population, the number of humans bitten, and thus malaria transmission.

The efficacy and persistence of residual insecticides vary with the type of surface sprayed (e.g. mud, wattle, wood, thatch, palm leaf or asbestos). Spraying according to specified criteria (relating to both insecticides and application procedures), public acceptance of house-spraying, the availability of appropriate and well maintained equipment, adequately trained spraying personnel, efficient supervision and strong financial support are necessary to ensure effectiveness.

7.1.2 *Criteria for selective application*

The considerable resources required for indoor residual spraying, combined with the potential for development of insecticide resistance and possible environmental hazards, necessitate a strict justification for its use as a control measure. Its use is therefore recommended only in high priority areas.

In areas where indoor residual spraying is to be carried out, the delineation of areas to be covered, and the frequencies and times of applications must be decided. Once spraying begins, there must be clear criteria for extending spraying into new areas, for the discontinuation of current spraying and for the maintenance of spraying beyond an initial set time period. The spraying programme must also be justified in terms of its cost-effectiveness.

In areas where spraying has been a major component of malaria control, its epidemiological impact can be assessed by correlating the quality and coverage of spraying operations with malaria trends. An aggregate indicator such as the annual parasite incidence rate should not be used as the sole criterion for continuing spraying. This is because the transmission and the burden of malaria are often focal and may vary with malaria endemicity and vector density/population within a small area, so that operational boundaries must be more precisely defined. Spraying operations may be limited to certain geographical areas, individual villages or groups of villages, or specific times of the year (e.g. during peak transmission periods). The size of the operational areas depends on local circumstances and is influenced by vector distribution, distance from important breeding sites, the flight range of the vectors, demographic features and the distribution of malaria. This information should be obtained for local situations whenever practicable.

Even within small areas, residual indoor spraying can be targeted at selected houses where the risk of transmission is highest, e.g. those near important breeding sites, or at the types of house or animal shelter that are most attractive to mosquitos or are most likely to favour human-vector contact. Spraying may also be confined to selected places within houses, such as thatched roofs, the upper parts of walls and the eaves, which are the preferred resting sites of many vectors and are also areas on which many insecticides persist for a relatively long time. On the other hand the biological efficacy of many insecticides persists for a shorter time on mud walls, so these may be avoided during spraying. Investigations may be needed to determine the impact of such selective spraying on the vector population and malaria incidence.

Selective use of insecticides would reduce costs and selection pressure for resistance; it would also allow more resources to be allocated to ensure better coverage by malaria control programmes in the vulnerable areas.

The current trend towards the introduction of insecticide-treated bednets, including their use as a replacement for indoor residual spraying, should be assessed within an epidemiological context. Any such change should be based on a comparative evaluation of insecticide-treated bednets against indoor residual spraying, taking into account effectiveness, acceptability and operational costs under various epidemiological conditions.

Reorientation of large-scale spraying programmes towards selective spraying will involve a reduction in spraying operations. This will necessitate adjustments in resource allocation and personnel, which might be accommodated by adopting other vector control methods that can make use of existing trained and experienced staff and material resources.

7.1.3 *Selection of insecticides*

The following factors need to be considered in the selection of an insecticide for indoor residual spraying.

Residual effectiveness: In areas of perennial transmission where indoor residual spraying with insecticide is considered, maximal residual effectiveness is desired.

Safety: The acute and chronic toxicity of the insecticide, its persistence in the environment and the accumulation of residues in the human body need to be taken into account.

Vector susceptibility: Susceptibility of the target vector population to the insecticide is essential.

Impact on disease: The ability of the insecticide to reduce the incidence of disease must be evaluated and ensured.

Excito-repellency: While the epidemiological consequences of the excito-repellent effects of insecticides are not fully understood, such effects must be taken into account in operational activities. They are considered disadvantageous if mosquitos are driven away from an insecticide-sprayed surface before picking up a lethal dose, but if repellency leads to a reduction in human–vector contact (by diverting mosquitos from humans to animals outdoors), then it could be beneficial.

Costs: Programme costs must be determined and documented. These should include the cost of insecticides and frequency of application, spray equipment, transport and labour.

Management of insecticide resistance: A knowledge of insecticides used for other purposes (as in agriculture), of resistance mechanisms in the target vector populations, and of compounds that favour the development of broad and narrow resistance can help guide the selection of insecticides with a view to minimizing resistance problems.

Specifications for insecticides: The efficacy of products used in public health depends on the physical and chemical properties of the formulated compounds. The specifications for pesticides issued by WHO[1] meet the requirements of public health programmes and may differ in many respects from the specifications for pesticides formulated for agricultural use. It is important that, for the control of malaria and other vector-borne diseases, consideration is given only to insecticides that meet the specifications issued by WHO. A report of conformity of a given insecticide to these specifications should be checked by an independent institution before the insecticide leaves the country of origin. This would guarantee that health programmes receive only compounds of the specified quality and would ensure maximal efficacy and safety.

Other factors: Odour, visibility of spray deposits, efficacy against nuisance pests and other factors influence the acceptability of house spraying to the community.

7.2 Personal protection measures

7.2.1 *Insecticide-treated material*

Insecticide-treated mosquito nets, curtains, hammocks, eave strips, papyrus mats and cloth are used as barriers or repellents to reduce human–mosquito contact (Box 9).

[1] Current specifications are available from the Division of Control of Tropical Diseases, World Health Organization, 1211 Geneva 27, Switzerland.

Box 9

Trials of insecticide-treated bednets

Pyrethroid-treated bednets have been effective in reducing malaria mortality and morbidity in certain areas, and may reduce transmission when used on a large scale. Trials in areas of moderate, low and seasonal transmission and extensive operational use in China have shown that insecticide-treated bednets can reduce the incidence of malarial attacks. In the Gambia there is evidence of reductions in child mortality, and in areas of intense perennial malaria transmission there is evidence for reductions in transmission, *P. falciparum* parasitaemia and the rate of reinfection. Insecticide-treated bednets can provide protection at individual and family levels, and when they are used widely in a community, the expected "mass killing" of mosquitos may protect even non-users of nets. Such a mass effect has been observed in some trials but not in others, lack of an effect presumably being due to immigration of mosquitos from neighbouring areas. An important aspect of community acceptance of treated nets is the reduction in biting nuisance from mosquitos and bedbugs.

Further studies to evaluate the impact of insecticide-treated bednets on disease are now being carried out in different epidemiological zones of Africa, and the results of these trials should be available in 1996.

The feeding and resting habits of the vector and the cultural practices and sleeping habits of the people are important determinants of the efficacy of personal protection measures. These measures will be most effective when the vectors are endophilic and/or endophagic; they are less effective (or ineffective) when the vectors are exophilic and exophagic and when people are not protected during the active period of the vectors.

The treatment of bednets with insecticides is intended to improve the protection provided by the net itself by preventing mosquitos from entering through any holes or biting through the net, and to kill any mosquitos that come in contact with the net. Other insecticide-treated fabrics are also intended to kill or repel mosquitos. Bednets may be used by people sleeping indoors or outdoors on beds or mats or in hammocks; they are portable and are suitable for use by travelling or nomadic populations.

Personal protection measures can be promoted using two different approaches. The first approach sees the insecticide-treated materials as a means of protecting the community that can be promoted through education and "sensitization" that motivate individual households to purchase their own bednets or other materials. Secondly, personal protection measures can be part of an integrated malaria control strategy aimed at a high level of coverage of a given population, supported fully or partially through public funds. Community acceptance of insecticide-treated nets and other fabrics often depends on their effect against other pests as well as mosquitos (e.g. bedbugs and head lice). In such circumstances, the development of resistance by these pest insects could in the long term compromise the acceptance of nets and hence their usefulness as a malaria control measure.

Pyrethroids are at present an important resource for bednet treatment. However, pyrethroid resistance has been detected in some insect species, including anophelines. The possible increase and spread of pyrethroid resistance are of great concern as they would affect the sustainability of this control approach. The use of pyrethroid insecticides for indoor residual spraying is not advisable in areas where pyrethroid-treated bednets are currently in use, or if their use is being contemplated, since it will enhance and speed up the development of resistance to pyrethroids. These concerns highlight the need for the discovery of new classes of compounds for the treatment of fabrics and for house-spraying.

So far only pyrethroid insecticides have been extensively tested for treatment of bednets or curtains as they are considered safe for humans. However, further studies are required on their toxicity (because skin and nasal irritation are reported to have been caused by some), and the effects of their long-term use are not known. More information is needed on the different dosages and formulations of insecticides, the effects of washing treated nets made of different fabrics and the costs and required frequency of re-treatment under different conditions.

The insecticide-treatment of material (e.g. for bednets) can be accommodated within the primary health care system and carried out under the guidance of trained village health workers, with a supporting mechanism for training, procurement of materials and entomological and epidemiological evaluation.

In general the cost of vector control operations based on insecticide-treated bednets (including the cost of the nets) approximates to that for house-spraying. If bednets are already owned by, or are paid for by, householders, the cost of the insecticide and its application is considerably less than that of a house-spraying operation. The cost of using treated curtains is lower than that of using bednets because fewer are needed per household. Supporting the community in the purchase of bednets and curtains by promoting (income-generating) local net manufacture, subsidized sales and revolving funds can make an important contribution to sustainability, as can the establishment of systems to help with re-treatment as appropriate to local circumstances.

7.2.2 *Repellents and domestic insecticides*

Repellents applied to the skin or to clothing may be used in combination with insecticide-treated bednets or curtains to increase personal protection. Repellents are usually needed to prevent biting in the early evening before people retire to bed or into houses and in the early morning before sunrise when people are not protected by nets; this is the case for rubber tappers and certain other outdoor workers.

The smoke from certain burning or smouldering plants and leaves has insecticidal properties, as do some plant extracts. Personal and domestic protection is also available in the form of repellents (coils, vaporizing mats) and insecticidal aerosols. These are all widely used against mosquitos by different communities and provide personal protection from mosquito bites for several hours. Insecticidal soaps and insecticide-treated ankle bands have also been tested. However, the majority of people in malaria-affected communities cannot afford the commercial products that are available.

Entomological evidence for the effectiveness of several repellents exists, but as yet there is no evidence that they are useful in reducing malaria incidence.

7.3 Larviciding and biological control

Larval control (e.g. with chemicals or biological agents) is relevant as the sole method of vector control only if a high proportion of the breeding sites within mosquito flight range of the community to be protected can be located and are accessible, and the breeding sites are of manageable size. Larval control can also be used to supplement the effects of other control methods.

Paris green (cupric acetoarsenite) was used in the successful eradication of *An. gambiae* from Brazil in the 1930s, but it is an arsenical compound and is too toxic to comply with modern standards. Temephos is much safer, but it also kills insect predators of mosquitos such as notonectids. Insect growth regulators (e.g. methoprene) and bacterial toxins (biocides, e.g. those produced by *Bacillus thuringiensis* serotype H-14) are much more specific to mosquito larvae. However, the formulations of *B. thuringiensis* currently available have low persistence. Preparations of the bacillus can be produced locally at relatively low cost, but there are problems of formulation and quality control. There is some evidence for the larvicidal efficacy of local botanical products (e.g. those obtained from neem, *Azadirachta indica*); these merit further investigation.

There is a long history of use of larvivorous fish for the control of mosquito larvae. Such fish, kept in confined water containers, have been effective in malaria control in, for example, Bombay (India) and Somalia. Their use could also complement other methods in an integrated control approach to increase the impact on the vector population and malaria. Experience in China and India has shown that rearing larvivorous fish and edible fish together reduces the larval population and provides income-generating opportunities. These help to sustain community involvement.

Floating layers of expanded polystyrene beads prevent mosquito breeding for long periods when used in confined sites such as cesspits and water tanks. They may be used effectively against *An. stephensi, Ae. aegypti* and *Culex quinquefasciatus.*

7.4 Environmental management

Environmental management approaches to vector control aim at modifying the environment to deprive the target vector population of its requirements for survival (mainly for breeding, resting and feeding). This reduces human-vector contact and renders the conditions less conducive to disease transmission. The management strategies and their impact may be short-term or long-term, and may require community involvement and multisectoral action.

In Malaysia, for example, the breeding of the malaria vector *An. maculatus* in streams has been effectively controlled by periodic flushing by means of small dams with siphons and sluice gates, and in Indonesia, changing the salinity of the breeding habitats of *An. sundaicus* has been used as an environmental management approach to vector control. Community-based environmental management projects for vector control have been undertaken in several countries, including India (*3*).

The environmental control of breeding habitats can have an impact on the vector population, and therefore on disease transmission, only if control measures cover a relatively high proportion of the breeding sites within vector flight range of the communities to be protected.

Experiences with methods of environmental management applied in the pre-DDT era should now be reviewed and their utility explored because they may have been effective in many situations, but were discontinued because of the expectations that malaria could be eradicated with DDT.

Development activities

Environmental change created during development activities can increase the risk of malaria. The environment may be altered as a result of agricultural practices, irrigation development (Box 10), or road and building construction projects; these activities can be the indirect cause of health problems. Borrow pits left after construction of roads and buildings, abandoned gem pits and mines are also potential mosquito breeding sites. Policies and legislation may be required to reduce the negative impact of development activities; adherence to such policies may require support from all levels, both national and international.

Housing: domestic and peridomestic environment

The location of settlements to avoid proximity to major vector breeding sites and promoting and supporting the design and construction of houses that reduce human-vector contact can minimize the risk of vector-borne disease.

The quality of housing (the design, structure and construction material) and its location in relation to breeding sites influence mosquito entry, resting habits and human-vector contact. Incomplete houses with open walls, wide or unscreened eaves, open windows and doors and no ceilings favour the entry of mosquitos. Mud or unplastered walls with cracks and

Box 10

Irrigation development projects

The building of dams and irrigation schemes may either hinder or favour the transmission of many vector-borne diseases; the latter is more common. Malaria has been strongly associated with irrigation projects in many countries.

In the initial phase of irrigation projects, deforestation and construction activities increase human-vector contact. This is often due to depletion of the wild animal population, which frequently serves as a source of blood-meals for predominantly zoophilic vectors, along with the introduction of a labour force that is generally not immune and may be inappropriately housed, so that exposure to vectors is increased.

Some species of vectors breed at the margins of poorly maintained canals with broken edges and vegetation cover, and in the pooling beds of irrigation canals or river beds below dams. Action at the planning and construction phase to ensure proper lining and shaping of irrigation canals and at the maintenance phase to repair and maintain damaged canal edges and to remove vegetation to allow free flow of water can minimize vector breeding and therefore malaria incidence.

During the maintenance of an irrigation scheme, the periodicity of water release for irrigation can be adjusted to allow flushing of mosquito larvae from pools in canal beds. This may be accommodated within the water management requirements of the health, agricultural and irrigation sectors. In some countries, for example Sri Lanka, larvae in the river beds below dams have been flushed out by means of sluice gates in specific situations to control focal outbreaks of malaria.

Intermittent irrigation, as used to produce periodic drying and wetting of rice fields when the soil has a low water-retention capacity, has been shown to reduce mosquito breeding by disrupting larval development. In China, intermittent irrigation has had no undesirable effects on the rice grain or on weed growth; instead it has improved crop yield and reduced water consumption, vector production and malaria incidence. Intermittent raising and lowering of water levels has been successfully used in the larval control of malaria vectors by the Tennessee Valley Authority (USA) and the Blue Nile Health Project (Sudan).

crevices and thatched roofs or walls also provide favoured resting sites for mosquitos. Communities living in malarious areas and those responsible for planning and constructing settlements and housing need to be aware of conditions that increase the risks of exposure to mosquitos so that they may consider taking appropriate preventive actions.

Unscreened water-storage containers and long-standing water bodies located in and near houses provide mosquitos with breeding habitats. In Bombay, India, the legally enforced screening of water tanks to prevent the breeding of mosquitos (e.g. *An. stephensi* and *A. aegypti*) has been successfully sustained for many decades.

Forest ecosystems

The forest ecosystem is a high-risk environment for malaria transmission, in particular where activities such as mining, agriculture at the forest fringe and deforestation favour human contact with efficient vectors. This situation is common to many countries in Africa, the Americas and Asia and the current problem of multidrug-resistant malaria in South-East Asia and South America is mainly forest-related.

While certain forest-related activities are on a large scale and are planned and sponsored by governments and other bodies, the exposure of individuals and communities to the risks of forest malaria may also be the result of small-scale activities, including traditional forest exploitation. Population movement (planned and unplanned) has also contributed to the problem of forest malaria. Personal protection methods, forest clearance and source reduction around workers' camps are some of the short-term vector control options.

Major forest-related activities (including reforestation) are occurring in many areas with the support of development agencies. Whether deforestation or reforestation is associated with the risk of malaria depends on the vector species, but the relationship needs to be further investigated, for instance in areas where the *An. dirus* complex is involved in transmission. An improved understanding of these issues could lead to identification of possible preventive actions, some of which might necessitate the development of appropriate policies and legislation.

8. Role of vector control in special risk situations

Situations in which there is a special risk of malaria can have a variety of causes:

- The movement into endemic areas of non-immune human populations – such as refugees and groups migrating for reasons of resettlement or economic opportunity – increases the number of people at risk of disease.
- Environmental changes with natural causes (e.g. extreme changes in temperature and unusual rainfall patterns causing floods or drought) may promote unpredicted and unusual increases in vector populations.
- Human activities may change the environment. For example, agricultural practices may cause ecological changes that create conditions conducive to increased malaria transmission.
- The declining efficacy of control tools is a cause for concern. Previously effective interventions may become ineffective or may be discontinued because of reduced sensitivity of the parasite to antimalarial drugs, reduced sensitivity of the vectors to insecticides or insufficient resources.

The following sections discuss the management of epidemics and drug-resistant malaria, including the use of entomological countermeasures appropriate to situations in which there is a special risk of malaria.

8.1 Malaria epidemics

8.1.1 *Indicators: detection of outbreaks and risks*

An efficient malaria control programme will be alert to the epidemiological, entomological and environmental changes that can lead to an increase in the incidence or risk of the disease. Useful indicators include:

- Mortality.
- Malaria fever/parasite rates: unusual increases in fever incidence, clinically suspected malaria cases and rates of laboratory-diagnosed malaria (especially in the transmission season).
- Increased consumption of antimalarial drugs.
- Proliferation of known vector breeding sites; if larval/adult vector densities are not monitored routinely by the vector control programme, indicators of potential breeding sites can be obtained from meteorological and agricultural sources. Entomological indicators can be used to confirm risks.
- A decline in the susceptibility of the target vectors to insecticides (this should be regularly monitored by all vector control programmes).
- Planning of water resource development projects accompanied by movements of populations for temporary labour or for land settlement.
- Uncoordinated or increased population movements of refugees, transmigrants, seasonal agricultural labourers, miners and settlers into periurban areas or areas where natural resources are exploited.
- Changes in agricultural and irrigation patterns.
- Poor maintenance of irrigation or drainage systems and water supply.

The most important elements in preventing epidemics are early access to information on changes in risk factors and swift mobilization of resources to minimize such changes before they can affect the human population. If the main risk factors are ecological and climatological (temperature, humidity, rainfall), then observation of changes in these factors could be complemented by monitoring entomological indicators in selected sensitive locations. The information obtained would alert the appropriate authorities to the potential risks, enhance vigilance for increasing numbers of cases of fever and malaria, and ensure that the authorities were prepared to react to the risks and outbreaks of disease.

The information management systems of control programmes should ensure the collection and management of relevant information to permit early recognition of outbreaks and emerging risks so that a rapid response is feasible.

The technologies being developed to forecast ecological and climatological changes (e.g. monsoon forecasting, satellite imaging/remote sensing) may be useful in the development of systems to predict the risk of malaria.

8.1.2 *Interventions*

Emergency actions to be taken in the event of an epidemic include management of the disease (by early detection and treatment of cases), chemoprophylaxis in certain circumstances, especially for high-risk groups (non-immune people and pregnant women) and the reduction of transmission through vector control.

In existing and emergent epidemics every attempt should be made to intervene immediately using:

- space-spraying (particularly where the human population density is high);
- indoor residual spraying;
- personal protection methods;
- larviciding and source reduction.

The impact of these interventions will depend on the stage of the epidemic at which action is taken.

Many epidemics occur as a result of large-scale movements of non-immune people into endemic areas in pursuit of better agricultural opportunities or for other reasons. Such epidemics can be avoided or contained through use of an efficient information system, good case-detection and prompt treatment, access to sufficient supplies of drugs and targeted vector control.

8.1.3 *Managerial aspects of epidemic prevention and control*

The main managerial tasks include arrangements for monitoring risk factors and for prompt communication of significant information to those responsible for making decisions and initiating action. There must be contingency plans that allow easy access to resources (funds, trained personnel, supplies) and rapid intervention when and where needed. It will be necessary to assign staff at the intermediate or field level (e.g. public health inspectors, entomological assistants) to assemble and review data and to transfer information, drawing specific attention to important observations, to an epidemiologist or entomologist at the intermediate or central level who can subject it to further analysis and offer support and guidance on interventions. A decision to intervene may be made at the intermediate or central level, depending on the situation, but close coordination is essential at all levels. The managerial process should also make provision for dealing with the risks of other vector-borne diseases that can have serious consequences, e.g. typhus, relapsing fever, dengue and Japanese encephalitis.

Delays in receiving emergency supplies often allow an epidemic to escalate. Therefore adequate amounts of emergency supplies should be located where they can be easily distributed. Stock rotation systems should be set up to ensure that perishable items are used before their expiry dates.

8.2 Drug-resistant malaria

Drug resistance has become one of the most important problems in malaria control. In some situations, resistance *in vivo* has been reported to all antimalarial drugs except artemisinin and its derivatives. Cross-resistance exists among mefloquine, quinine and halofantrine.

Multidrug resistance necessitates the use of alternative drugs that may be expensive and difficult to administer, and often have adverse side-effects. In some parts of the world the artemisinin group of drugs has become the first line of treatment, and these drugs are currently being used indiscriminately for self-treatment of suspected uncomplicated malaria. Under such circumstances, resistance to artemisinin derivatives may be anticipated in less than a decade, which would compromise the therapeutic efficacy of these drugs in the treatment of severe and complicated malaria. Many populations are at risk of multidrug-resistant malaria; it is associated with an increased incidence of severe and complicated cases, increased mortality, higher costs of treatment and the risk of drug side-effects because of the need to use the newer antimalarials. The problem is most acute in the two areas where resistance to chloroquine first emerged, i.e. the Indo-Chinese peninsula and the Amazon region in South America.

8.2.1 *Development and transmission of drug-resistant malaria*

Multidrug resistance in South-East Asia and South America is associated with:

- indiscriminate use of drugs, leading to increased selection pressure;
- certain occupations and habits that increase the risk of exposure to mosquitos: people may be outside during the peak biting periods of the vectors because of the hot humid climate or for work (as in rubber plantations in the early morning), or may sleep in unprotected shelters located near water-filled mines which serve as mosquito breeding sites (e.g. gem miners);
- areas without transmission control or in which control is ineffective.

In the forested foothills in South Asia (Bangladesh, India) and South-East Asia (Myanmar, Thailand, Viet Nam) mosquitos of the *An. dirus* group and *An. minimus*, which are often associated with transmission of drug-resistant malaria, have increasingly adapted their feeding habits to the habits of the people. These mosquitos are highly anthropophilic and are able to maintain intense transmission at low biting rates.

8.2.2 *Role of vector control in areas of drug resistance*

In areas in which drug-resistant malaria occurs, all possible efforts are needed to curtail the problem. High priority should be given to identifying methods that increase early case detection and reduce the risks of infection. Most multidrug-resistant malaria is currently correlated with transmission through highly efficient vectors (e.g. of the *An. dirus* group), which are exophilic and forest-breeding and against which indoor residual insecticide-spraying may have limited impact. Where populations are mobile, the effect of insecticide-treated bednets may also be limited. However, if such populations can be motivated to use treated bednets and preferably repellents too, some reduction of transmission may occur. Populations working in previously forested areas that are being reforested or replanted are relatively stable. In such circumstances, individual protection through treated bednets may have an important role, and source reduction, if relevant, may be promoted in the peridomestic environment.

In some situations, including non-forest rural areas and urban areas with endophilic vectors, selective vector control with indoor residual spraying and other methods could be useful in controlling any foci of drug-resistant malaria that emerge.

9. Monitoring and evaluation of vector control activities[1]

If the administrators of a malaria control programme are to assess the efficacy of vector control operations and adjust policies to make the most efficient use of scarce resources, reliable indicators are required. Data should be obtained through a well structured health information system, and should be of sufficiently high quality to guide and influence the decision-making process. Information requirements for monitoring and evaluating malaria control programmes, including the vector control component, were discussed recently by a WHO Study Group (*2*).

Appropriate indicators need to be defined by each programme. The indicators chosen should be limited in number, readily interpretable and operationally useful. In some circumstances, more detailed evaluation will be needed to solve specific problems, and to enable major decisions to be made, such as whether control strategies should be withdrawn or changed or a new control method introduced.

Monitoring of vector control should include an assessment of routine operations (e.g. resources utilized and their cost), outcomes in terms of operational achievements (i.e. coverage and its quality), the

[1] For further information on many of the indicators used in monitoring and evaluating vector control activities, see references *4–7*.

entomological impact and impact upon the target disease. The operational and entomological indicators selected should provide explanations of why, how and where an intervention may (or may not) produce an expected epidemiological impact. Monitoring also establishes the need for, and relevance of, training and research activities.

A minimum of detail on costs and impact will permit assessment of the cost-effectiveness of an intervention. In addition, evaluation of the impact will point to the value of continuing a particular intervention or the advisability of choosing another option.

9.1 Indicators of operational and entomological impact

Entomological indicators and techniques have been described in previous WHO publications (*4–7*); the applications and limitations of those currently used are reviewed briefly in section 10 of this report. Indicators and techniques for monitoring cost-effectiveness have been described by Phillip, Mills & Dye (*8*).

For specific vector control methods, Table 1 lists appropriate operational and entomological indicators that may be monitored regularly (*R*), selectively for specific purposes (*S*) or for trends (*T*).

Table 2 shows the types of indicator expected to be affected by three different interventions. An apparent lack of effect should be a warning signal: the intervention may be ineffective (and should therefore be further evaluated) but it is also possible that information on the effect of the intervention has not been properly collected. In the latter case, steps should be taken to improve the training of personnel responsible for collecting or interpreting the results.

9.1.1 *Indoor residual spraying*

Dosage and quality
Checks must be made to ensure that the recommended dosages of insecticide are being used. The quality of insecticide should be checked by suspensibility tests, which may be followed by chemical analysis if the quality is still in doubt. Visual observations of insecticide residue (if the insecticide leaves a deposit) and bioassay results will indicate the availability of insecticide to the mosquitos. If the results of bioassays suggest inadequate responses, then comparisons are needed between houses sprayed under direct supervision and those sprayed under field-operational conditions, without such supervision.

Coverage
The percentage of houses and rooms sprayed in relation to the targeted number of houses or rooms must be recorded regularly. Poor coverage indicates operational shortcomings and appropriate action is needed to overcome the deficiencies. The proportion of houses replastered after spraying also needs to be checked.

Table 1
Operational and entomological indicators for monitoring vector control

Vector control method	Operational monitoring	Entomological monitoring
Indoor residual insecticide-spraying	dosage (*R*) coverage (*R*) timing (*R*) persistence (*R*, *T*) status of equipment (*R*) resources utilized (*R*) cost (*R*)	daytime indoor resting (*R*) human-biting rate (*T*) human blood index (*T*) parous rates (*T*) sporozoite rate (*S*) insecticide susceptibility status (*R*) adult mosquito density (*T*)
Impregnated mosquito nets	dosage (*R*) coverage (*R*) use (*R*) persistence (*R*, *T*) resources utilized (*R*) cost (*R*)	biting cycle in relation to sleeping habits, use of repellents (*S*) human blood index (*T*) insecticide susceptibility status (*R*) human-biting rate (*T*) sporozoite rate (*S*) adult mosquito density (*T*)
Space-spraying	coverage (*R*) area of influence (*R*) resources utilized (*R*) cost (*R*)	human-biting rate[a] adult mosquito density (*R*) parous rates[a] insecticide susceptibility status (*R*)
Larviciding	coverage (*R*) persistence (*R*, *T*) resources utilized (*R*) cost (*R*)	presence and density of larvae (*R*) adult mosquito density (*R*) insecticide susceptibility status (*R*)
Source reduction	total number of potential breeding sites (*R*) number eliminated (*R*) resources utilized (*R*) cost (*R*)	adult mosquito density (*R*)

Indicators may be monitored regularly *(R)*, selectively for specific purposes *(S)* or for trends *(T)*.
[a] When space-spraying is continued for at least a few weeks.

Timing

Entomological indicators, such as the indoor-resting density of female mosquitos and their blood-digestion stages (i.e. the proportions of blood-fed, semigravid and gravid adults) should be related to the spray status of houses to indicate whether spraying has been effective and whether monitoring is being carried out within the period of expected efficacy of the insecticide. It is also necessary to check whether the insecticide has been applied at the appropriate time in relation to the onset of transmission.

Table 2
Aspects of mosquito populations expected to be affected by three types of control operations

Indicator	Larviciding	Indoor residual spraying	Impregnated mosquito nets
Larval presence and abundance	+	–	–
Adult density	+	+	+/–
Adult survival/ sporozoite rate	–	+	+/–
Human biting in protected houses	NA	+/–	+

NA, not applicable; +, effect expected; –, no effect expected; +/–, effect doubtful or conditional on other factors.

Equipment
The status and performance of spraying equipment should be checked regularly to ensure adequate performance under operational conditions.

Cost
Resource utilization (salaries, per diems, spray equipment, insecticides, cost of transport) should be recorded to assess cost implications and to provide information for cost-effectiveness analysis.

Entomological indicators
House-spraying targeted against endophilic vector populations that rest on the sprayed surfaces is expected to reduce the number of infective mosquitos that enter a house and the number that, having bitten infected people, leave the sprayed house. This would reduce the sporozoite rate, the entomological inoculation rate and malaria transmission through a reduction of adult mosquito density, the indoor resting population and human–vector contact.

Information concerning the indoor-resting population and mosquitos collected from exit traps, including details of their blood-digestion stages, must be related to the timing of spraying operations and the status of spraying of the houses sampled. High numbers of unfed mosquitos with fewer or no fed, semigravid or gravid mosquitos in sprayed houses may imply an influx of newly emerged adults on which the insecticide has not yet had an effect. A high proportion of gravid mosquitos indicates an inadequate response of the vectors, possibly due to vector resistance (which needs to be clarified by insecticide-susceptibility tests) or to an inadequate effect of the insecticide because of poor spray coverage. These possibilities can be checked by use of bioassays and other operational indicators.

High vector densities observed in sprayed areas, even when a significant impact has been recorded in sprayed houses examined entomologically, suggest either that mosquitos may be moving in from neighbouring unsprayed areas, or that there have been new emergences from breeding sites in the sprayed area. Data on parous rates will indicate whether the second possibility is likely.

Detection of survivors in the WHO standard susceptibility test (see footnote, page 41) indicates the presence and selection of individuals in the vector population that are resistant to the insecticide involved. However, detection of resistance, even at high levels, by this test is not on its own a criterion on which to base a decision to change to alternative insecticides. The data must be assessed along with other indicators of entomological, operational and disease impact to determine the relative importance of resistance as against operational shortcomings and other factors.

9.1.2 *Insecticide-treated bednets and curtains*

Dosage
It is important to ensure that the recommended dosage is applied.

Coverage/usage
Records should be kept of the percentage of households that have accepted the intervention, the percentage of people in each house who use the nets every night (with spot checks including unobtrusive observations to verify recorded data), and the percentage of nets and curtains that are washed and re-impregnated. Poor acceptance or use will compromise the value of this vector control method.

Persistence
The biological efficacy of the insecticide should be checked by bioassay tests to provide guidance on the appropriate periodicity of treatment and for indirect monitoring of the quality of treatment. Measurement of the susceptibility status of the vector population by the standard tests will provide information on the appropriateness of the insecticide used.

Costs
All costs must be documented, whether or not the direct costs of the entire bednet programme (nets, insecticide and cost of personnel) are being met by the malaria control programme.

Entomological indicators
The primary objective of using insecticide-impregnated bednets is the prevention of infection by reducing human-vector contact. Human-biting rates measured as an indicator of such contact could be overestimates of the true biting rates if mosquitos are diverted from people sleeping under nets to the mosquito collectors. The likelihood of this may be minimized

by locating the baits sufficiently far away from people sleeping under nets. The human blood index determined from samples of resting mosquitos captured both indoors and outdoors can provide a more reliable estimate of human-vector contact, provided that adequate samples from representative sites are obtained. Despite the inherent biases and the limitations of these techniques, the data on trends in human-biting rates and human blood indices are useful for evaluating the impact of impregnated bednets.

A knowledge of vector biting patterns and peak biting times in relation to people's sleeping habits is required for different epidemiological situations before and after the introduction of bednets. This helps in anticipating the impact of bednet use and in the observation of any changes in vector feeding habits due to bednet use. There may be a need for supplementary measures such as use of repellents if the peak biting time occurs before people go to sleep. If supplementary measures are not feasible, the validity of the intervention must be reconsidered.

Monitoring of human-biting rates, human blood indices and the adult mosquito density is relevant only if a large proportion of the population use bednets in a particular area and when a reduction of mosquito density through a mass-killing effect can be expected.

9.1.3 *Space-spraying*

Coverage

The influence of the insecticide on the target area must be monitored (by aerial bioassays) and the impact on vector densities must also be recorded.

Timing

The timing of space-spraying must be related to peak activity of the mosquitos.

Weather conditions

Wind direction, rain and air convection currents at the time of (outdoor) spraying have an important influence on the effectiveness of the operation and need to be taken note of in day-to-day planning. Outdoor space-spraying should be avoided during rain and strong wind. Treatment should take place under conditions of temperature inversion and during periods of maximum mosquito activity, i.e. in the evening and early morning.

Insecticide droplet size

Insecticide droplet size should be measured and modified as necessary to ensure an optimal effect of space-spraying.

Cost

Resource utilization (salaries, per diems, spray equipment, insecticides and carrier substances, cost of transport) should be monitored in relation to outcome.

Entomological indicators
Adult mosquito densities may be monitored before and after the application of insecticide in order to assess its impact; monitoring of human–vector contact may be relevant only when space-spraying has been carried out for some time. Monitoring should be within the boundaries of the area the insecticide is expected to reach with the different types of spray machines and insecticide formulations. Aerial bioassays are used to assess the immediate impact of the spraying on the adult mosquito population.

9.1.4 *Larviciding*

Coverage
The percentage of breeding sites treated in relation to the total number of breeding sites within the area of protection gives a figure for the coverage.

Timing and frequency of application
Relevant indicators should be monitored to ensure that application is timed to coincide with the period of high transmission and high larval density and its frequency is appropriate to the duration of development of the aquatic stage.

Persistence/efficacy
The efficacy of the larvicide applied should be measured (see "Entomological indicators" below). The persistence and efficacy of different larvicides need to be compared so that the most cost-effective can be chosen.

Cost
Resource utilization (salaries, per diems, spray equipment, insecticides, cost of transport) should be monitored in relation to outcome.

Entomological indicators
Measurements of larval density should be made and bioassays carried out in representative sites in treated and untreated areas and/or before and after treatments. The comparison of control and treated areas will indicate whether observed effects are due to the intervention (and reflect the quality of operations) or result from natural causes such as rains or other confounding factors. Larval susceptibility tests on the compound are also important.

The effects of larval control on the adult population must be clarified. Sampling must be planned to avoid the effects of migrant mosquitos from neighbouring unsprayed areas. Monitoring of adult mosquitos should also be undertaken in treated and untreated areas and before and after treatments. If monitoring shows that larval intervention has no effect on the adult population in the operational area, the operation should not be continued.

When different types of vector breeding site occur in the same operational area, a knowledge of the relative contribution of each type to the emergence of adults will help in targeting those that contribute most to the adult population. Similarly a knowledge of the relative effectiveness of each method in a given breeding site or habitat will enable the most cost-effective methods to be selected. The contribution of different breeding sites to vector production can change for various reasons, for example as a result of larval control; it should therefore be checked periodically, especially if the impact of the intervention is uncertain.

9.1.5 *Source reduction and improved housing*

Source reduction

Unless a high proportion of the breeding sites within the flight-range of vectors can be eliminated, source reduction will not have a great impact on the adult population. Removal of any water bodies (e.g. in the peridomestic environment) that act as breeding sites should nevertheless be encouraged. When the contribution of such measures to the overall impact of vector control activities is expected to be small, monitoring is unnecessary.

Improved housing and mosquito-proofing of houses

It is important to obtain information on the relationship between houses built to different standards (design, structure, construction material, mosquito-proofing) and distance from important breeding sites, densities of indoor-resting vectors, human–vector contact and malaria incidence. Evidence of any association may be used to convince decision-makers, particularly those who plan housing and settlements, to take necessary actions to improve housing quality and to choose appropriate locations for settlements.

9.2 Indicators of impact on disease

The objective of any intervention is the prevention and reduction of malaria morbidity and mortality via transmission control. Therefore, the monitoring of this outcome is essential. The type of indicator used will depend upon the method of intervention, target population and expected outcome (Table 3). Since the main impact indicators will be malaria incidence, morbidity (including disease severity) and mortality, it is important to measure variations in these indicators, at least in the age or population groups that are at greatest risk.

The procedures and criteria for the assessment of fever and collection of blood slides should be standardized and subject to quality control to allow monitoring of the impact of interventions with minimal bias.

In areas where vector control has been carried out for some time, it is necessary to determine whether current vector control activities continue to be effective. Although a rigorous study design is desirable, this may be

Table 3
Selected indicators for monitoring the impact of vector control on disease

Vector control method	Target population	Outcome indicator
Indoor residual spraying	Number of people in the area of spray operations Number of people in the houses sprayed	Percentage reduction in malaria incidence (fever, severe malaria, parasitaemia) in target areas or groups Infant parasite and spleen rates in endemic areas Percentage reduction in malaria mortality
Impregnated mosquito nets	Number of people in the area of bednet operations Number of people living in houses in which nets are used Number of people using nets	Percentage reduction in malaria incidence (fever, severe malaria, parasitaemia) Percentage reduction in malaria incidence in target groups (e.g. children) Percentage reduction in malaria mortality and all-cause mortality
Larviciding	Number of people in the operational area	Percentage reduction in malaria incidence (fever, severe malaria, parasitaemia)

difficult. For example, data on comparable areas to serve as controls may not be available, so it may be impossible to make comparisons of areas before and after treatments, or comparisons between different areas and populations. In such circumstances, an unbiased retrospective evaluation of the impact on malaria of interruptions and reinstatements of vector control should be attempted. It is often possible to make use of data that already exist but have not been analysed for this purpose. Where evidence suggests that a particular vector control intervention is ineffective, interruption of that intervention is an option, provided that appropriate plans for alternative protective cover of the population (if needed) are in place.

9.3 Integrated use of control methods

In selective vector control, more than one vector control method, each with a different level of efficacy and different requirements, may be used in a given area simultaneously or consecutively. The operational units for each method will depend on the level of stratification and selectivity in the use of the method; they may be major areas, clusters of villages, high-risk populations, households, individuals or water bodies of different sizes.

Certain vector control methods, such as larval control and environmental management, may not on their own have an adequate impact in all situations; the complementary or synergistic effect of two or more methods should therefore be considered. Use of several methods necessitates the monitoring of indicators that measure the effect of each method on its immediate or direct target as well as its relative contribution to the overall effect of vector control activities on both the vector population and the disease. This information will enable the most cost-effective interventions to be selected.

10. Entomological parameters and techniques

Entomological parameters and techniques are often inappropriately used. Data are often collected that are neither used nor interpreted to guide programme activities. There is therefore a need to make a critical assessment of the applications and limitations of these parameters and techniques, whether they are used in epidemiological investigations, to collect baseline data or to monitor and evaluate interventions. For further details and related entomological terminology, the reader is referred to previous WHO publications (*4–7*).

10.1 Detection and monitoring of insecticide resistance

The standard WHO insecticide-susceptibility test is used to detect and monitor insecticide resistance.[1] New reports of resistance from the field must be confirmed and the vectors checked for potential cross-resistance to other available insecticides. The currently used WHO test does not simulate the actual exposure of the wild vector population to the field dosages of insecticides used in control operations. Therefore data based on the WHO susceptibility test alone should not be used as the sole criterion for making a decision to change insecticides. Instead, positive test results, such as the survival of vectors at the discriminating dosages, should be regarded as an indicator of resistance that will need confirmation and further monitoring. The effects of vector resistance to insecticides, especially at high levels, should also be studied in terms of the response of the vector population and malaria incidence when the insecticide concerned is used in field operations.

Identification of the resistance mechanisms involved helps to predict potential cross-resistances at an early stage and can provide guidance for resistance management. Field use of the simple biochemical assays now

[1] Further information on WHO susceptibility tests and contact bioassays can be obtained from Malaria Control, Division of Control of Tropical Diseases, World Health Organization, 1211 Geneva 27, Switzerland.

available for identifying certain resistance mechanisms, coupled with the use of synergists (which inhibit specific detoxification enzymes) and laboratory-based metabolic studies, can be helpful in this respect. Biochemical assays allow individual mosquitos to be tested for a number of resistance mechanisms. These tests, along with the standard WHO test, have been effectively used to detect incipient resistance and potential cross-resistance in several disease vectors, including malaria vectors. Biochemical tests are, however, no substitute for the standard test for detecting and monitoring resistance.

10.2 Bioassays

The WHO contact bioassay test (as distinct from the susceptibility test) checks the effectiveness of residual insecticide deposits over time following treatment, and helps determine re-treatment schedules. Bioassays of sprayed surfaces or insecticide-treated material are also a means of monitoring the efficiency of operations.

10.3 Adult density

Many methods exist for sampling mosquito populations to determine adult density, including animal-baited traps, direct collection from human bait, spray sheet collection after indoor pyrethrum spraying, and light traps; each has inherent biases. The concurrent use of several methods overcomes some of the biases in individual techniques and allows sampling of populations and subpopulations that have different behavioural characteristics and occupy different habitats.

Vector density can also be estimated from biting or resting indices.

10.4 Resting indices

Pyrethrum spray sheet and hand collections of mosquitos are used in sampling daytime indoor-resting populations. Some mosquitos may leave houses after feeding or be forced out of houses even during the night by irritant insecticides or by smoke from cooking. Mosquitos can be trapped as they leave the houses using window (exit) traps, veranda traps or “Colombia curtains” (which can be dropped from the eaves of houses). Such collections provide information on indoor-resting behaviour and the effectiveness of indoor residual spraying, and relate the resting collection to the total number of mosquitos that entered a house, and probably bit, during the night. However, pyrethrum spray sheet collections and exit traps may not be suitable for monitoring mosquito activity in all types of houses.

Indoor hand collections using torches and aspirators are subject to individual collector bias and are generally less effective than pyrethrum spray sheet collections. Hand collections are used to obtain live mosquitos for specific investigations. Outdoor sampling is generally not very productive because of the large areas involved; however, some anopheline species can be concentrated in artificial outdoor-resting sites, such as "pit shelters" and other specific microhabitats.

10.5 Mosquito age and survival rates

Mosquito age and survival rates are important determinants of vectorial capacity and transmission. They can be affected by interventions such as the use of insecticides.

In estimating the probability of daily survival of mosquitos on the basis of parous rates, the population is assumed to be at a steady state as regards gain and loss due to migration, new emergence and mortality. The bias resulting from a temporary reduction in parous rates due to a sudden abundance of newly emerged mosquitos may be minimized by pooling samples collected regularly over an extended period. Counting the dilatations on the ovarioles to determine the number of gonotrophic cycles completed is difficult and time-consuming and is not suitable for routine work. The mark-release-recapture method, for which a large number of mosquitos are needed and the capture rates are generally low, is useful mainly in special studies. Survival estimated using females held in cages is also useful in special studies, but does not represent the field situation. There is therefore a need for improved methods to measure mosquito age and survival.

10.6 Human-vector contact

Human-vector contact may be measured either directly, by collecting mosquitos landing on or biting people, or indirectly, by determining the human blood index or, from an epidemiological point of view, the entomological inoculation rate.

10.6.1 *Human landing/biting rate*

Catching mosquitos as they land on people is tedious, difficult to supervise and costly as a means of estimating human-biting rates, and can expose those acting as baits or collectors to an increased risk of disease. Use of this method may nevertheless sometimes be necessary.

The use of light traps placed beside occupied untreated bednets is a suitable substitute for landing catches for some vector species, but others respond poorly to the traps. Sampling using human baits protected by double nets has been shown to be less effective than making direct landing catches in most instances. The results obtained by any proposed alternative method should be adequately checked for their correlation with estimates made from human landing catches to ensure that the human-biting mosquito population is effectively assessed and monitored. Some of the limitations of the use of human landing catches are discussed in section 10.9. These limitations highlight the need for improved techniques for more accurate estimation of human-biting rates.

10.6.2 *Human blood index*

The human blood index is an important determinant of vectorial capacity and is measured by identifying the sources of blood-meals in samples of resting mosquito populations. The precipitin test and enzyme-linked immunosorbent assay (ELISA) are currently widely used; ELISA is considered more sensitive than the precipitin test as it allows identification of the sources of almost all visible blood-meals. A gel-diffusion method has also been found very useful and affordable and is in effective use in some countries. DNA "fingerprinting" by means of the polymerase chain reaction to identify the individual human from whom a blood-meal was taken may be useful in detailed studies on personal protection provided by bednets, as well as in other special micro-epidemiological studies on vector-borne disease transmission.

The use of the human blood index requires adequate and representative samples of fed mosquitos from different resting sites. The ability to identify sufficient numbers of blood-meal sources from field collections may be enhanced by the development of techniques that can identify the sources of blood-meals after longer periods of digestion and storage.

10.7 Mosquito infection rates

The detection of plasmodial sporozoites of human origin in mosquito salivary glands is important in determining vector status. The sporozoite rate can be used to estimate the sporozoite inoculation rate of the human-biting mosquito population and is a key parameter in the quantitative analysis of natural transmission.

Salivary gland dissection to detect plasmodial sporozoites is time-consuming, requires appropriate technical skills and needs to be undertaken on fresh material. This limits the sample size that can be handled, and is a problem when sporozoite rates are low. However, the technique has proved useful over the years in the establishment of vectorial status. Identification of the parasite species is not possible using this technique, which is a drawback where more than one species of *Plasmodium* (human or simian) occurs in a single area or anopheline species.

The immunodiagnostic technique ELISA, based on monoclonal antibodies to circumsporozoite proteins (CSPs), allows rapid estimation of sporozoite antigen rates and densities in large samples of mosquitos. The ELISA requires laboratory-based facilities, higher financial inputs than the dissection method and stringent quality control, but it is species-specific. The technique has been effectively used to incriminate suspected malaria vectors and to establish their role in transmission in diverse situations in a number of countries in Africa, Asia and South America. Large samples can be processed that have been collected simultaneously from many areas over a considerable period of time and then cryopreserved or air-dried. Confining the assays to the thoracic portion of the mosquitos avoids detection of CSPs in the late oocysts, but does not differentiate between the salivary gland and haemocoel CSPs. In areas with very low sporozoite rates, CSP antigens are detected more easily in pooled samples. Sporozoite antigen rates have at times been overestimated because of false-positive results. Reports of antigenic variation with polymorphism for CSP antigens, as in *P. vivax*, necessitate the use of different monoclonal antibodies against different parasite strains. The combined use of salivary gland dissections and ELISA can overcome the limitations and biases involved in each technique.

10.8 Entomological inoculation rate

The entomological inoculation rate is the product of the sporozoite rate and the human-biting rate and is the most important and epidemiologically meaningful estimate of human-vector contact. In areas where there are several vector species and in which there are large differences in biting rates and human blood indices between villages, the entomological inoculation rate is the most appropriate way in which to establish the relationship between the entomological and parasitological variables. The entomological inoculation rate can be used to determine the entomological impact of an intervention. However, its measurement may not be practical as part of routine control activities.

10.9 Measurement of malaria transmission

The intensity of malaria transmission and changes in transmission or its potential following interventions may be determined from infection rates in mosquitos and humans, vectorial capacity, or the individual components of vectorial capacity. Some of these variables are more appropriate than others for certain interventions and epidemiological situations.

Human-biting rates, vector habits, the probability of vector survival, and sporozoite rates are incorporated in the formulae used to calculate basic reproduction rates, inoculation rates and vectorial capacity. As many of these parameters are difficult to measure in the field without bias, estimates are sometimes unreliable, particularly when the behaviour of vectors is not random. Such estimates may be relevant to specific research questions but most are not suitable for use in general programme evaluation.

Selection of key parameters for measuring malaria transmission depends on the control method. For example, the introduction of an intervention that affects human-vector contact can sometimes render landing rates of mosquitos inappropriate as a measure of the biting rate or of transmission. For instance, in a preliminary trial of untreated bednets for control of malaria and filariasis, significant reductions were recorded in the sporozoite rate and human blood index, suggesting reduced human-vector contact; this was in contrast to the human-biting rate estimated by landing catches, which had almost doubled (*9*). In this example, the biting rate as estimated by landing catches of mosquitos on unprotected collectors was not appropriate as a "key parameter". After the introduction of bednets, most of the human population were no longer accessible to host-seeking mosquitos; this increased the relative availability of the unprotected collectors to mosquitos, so that landing catches did not provide a valid estimate of the true biting rate.

10.10 Choice of entomological and parasitological parameters

The selection of parameters to be monitored for evaluation of vector control depends not only on the type of intervention, but also on the force of infection in an area. It is often not possible to obtain the quantity of samples that would be required to estimate biting rate, human blood index and mosquito survival.

In highly endemic areas, large changes in vectorial capacity may not have a dramatic impact on the parasite prevalence in the human population. In areas of low endemicity, where sampling and analysing the mosquito population become more difficult, the errors in estimates can increase; but in this situation small changes in vectorial capacity or inoculation rates are usually reflected in changes in parasite rates in the human population. Where the proportion of symptomatic relative to asymptomatic infections is high, most new infections are expected to be detectable at medical institutes and facilities if efficient health care networks exist for case-detection. Thus the entomological parameters for use in conjunction with parasitological or clinical parameters to evaluate interventions need to be carefully selected according to the epidemiological situation.

10.11 Design for evaluating interventions

Small variations in malaria transmission intensity between areas as well as large temporal fluctuations are important features of malaria transmission. The differences in parasite prevalence between adjacent villages may reflect different forces of infection resulting, in part, from differences in local vector biology.

The design of experiments for evaluating interventions must recognize these pre-existing differences in transmission by ensuring that: malaria transmission is monitored over a sufficient period of time; a single area (or village) is not used alone as a historical control; and sufficient units (e.g. villages) are sampled to enable statistically significant conclusions to be drawn about the effectiveness of interventions (*10*). The number of villages required to provide statistically significant results for valid interpretations will depend on the expected effect of an intervention.

The size of the treated and control areas to be sampled must be chosen to take account of the expected abundance and geographical distribution of the vector species. A knowledge of the estimated mosquito flight-ranges can be helpful for this purpose.

Methods for conducting field trials of interventions against tropical diseases have been described elsewhere (*11*).

11. The role of entomological services in malaria control

Entomological expertise is essential for guiding and supporting vector control activities, i.e. for planning, implementing, monitoring and evaluating vector control. Its contribution depends on the objectives and targets of malaria control, and the available information. For the contributions of entomological services to be cost-effective, their activities must be closely linked with the operational and other epidemiological aspects of malaria control.

In a malaria control programme that functions properly, entomological services should provide information on:

- the local vectors (incriminated or suspected), including the members of species complexes and their basic biology, temporal and spatial variations in abundance and role in transmission;
- the biting activity of vectors over time and space and their resting behaviour;
- vector susceptibility to insecticides considered for use;
- the effect of climatic factors (including seasonal variations of temperature, relative humidity and rainfall) on the breeding and survival of vectors;
- the type and location of vector breeding sites, their contribution to vector production, and the practicability and relevance of larval control;
- the efficacy and suitability of control methods at local level.

They should also support programme activities by:

- monitoring environmental risk factors and their potential to enhance disease transmission at local level;
- examining the knowledge, attitudes and practices of the human population in relation to mosquitos and vector control;
- monitoring current vector control activities by identifying entomological and operational reasons for successes or failures of interventions;
- providing feedback for remedial action.

Other roles of entomological services, in relation to monitoring and evaluation, epidemics, community and intersectoral mobilization, and operational research, are referred to elsewhere in this report.

The nature and extent of entomological activities, including monitoring, evaluation or surveillance, will depend on the planned or current vector control programme, the infrastructure or institutional arrangements under which malaria control is undertaken and the available resources. There will therefore be differences between countries, in particular between countries in Categories I and II.

11.1 Category I countries

In most Category I countries, entomology plays a limited part in malaria control programmes. But there is usually some degree of expertise and experience available at local universities and research institutes, which can support control programmes by providing relevant information and guidance and by undertaking collaborative operational research and training. Close links and interaction between local institutes and malaria control personnel are vital if there is to be adequate entomological information available on which to base decisions about control programmes. Specific examples of the needs for short-term and immediate entomological support are described below.

Identification of ecotypes
Entomological support is essential for macro-level planning, i.e. identification of the major ecotypes in relation to their potential to contribute to the overall malaria problem.

Introduction and monitoring of vector control strategies
The current emphasis on the use of insecticide-treated bednets and other treated materials demands a review of the relevance of this strategy. Indicators for bednet use should be identified and the effectiveness of nets analysed before their large-scale use is contemplated. Vector control strategies must be monitored to check whether they are maintaining their effectiveness, and when, where and why they fail. For this purpose the monitoring of entomological indicators and a knowledge of their relationship to the relevant operational and outcome indicators are required.

In some situations micro-level planning will be necessary to allow more focalized targeting of interventions (e.g. bednet use) in the areas, populations or individuals most at risk of disease.

Monitoring of vector-related indicators
In areas at risk of malaria epidemics, it is necessary to monitor vector-related indicators that can contribute to early warning systems at local level, to investigate and delimit current epidemics and to select appropriate control methods and insecticides.

Training activities
Training and supervision of staff and the community in personal protection measures, including procedures for insecticide treatment of bednets and other materials, may be required to ensure satisfactory performance and high rates of participation. Entomological personnel should also participate in health education and other activities to create awareness and to draw the attention of key groups – decision-makers,

planners of development activities (including urban development) and communities – to the malaria problem. For example, these groups need to be made aware of the environmental causes and risks of malaria and other vector-borne diseases, the transmission cycle and the measures that can reduce the risk of disease.

11.2 Category II countries

Category II countries should generally already have the entomological expertise required to provide essential entomological information and guidance, as indicated earlier in this section (page 47), and to make effective use of the parameters and techniques discussed in section 10. However, most of these countries need to reorient their services and examine the cost-effectiveness of their control efforts in an unbiased way.

12. Managerial aspects of malaria vector control and entomological services

12.1 Management of vector control

A major drawback in most malaria control programmes is weak management. A good management team should have a chain of command, a clear definition of objectives and responsibilities and adequate resources to manage these responsibilities, and should constantly evaluate its efficiency in meeting objectives. In many countries the management infrastructure for selective use of vector control methods does not yet exist. Suitable managerial skills are needed to accommodate the current trends in vector control, to reorient vector control programmes that were originally established to support malaria eradication efforts and were structured accordingly, and to provide an adequate supporting environment for programme implementation as required under the Global Malaria Control Strategy.

Important general issues in the management of any activity including vector control are:

- planning, guiding and monitoring implementation;
- development of appropriate strategies and standardized criteria for implementation;
- ensuring adequately trained human resources to implement programmes;
- development of career structures so as to retain trained and skilled personnel for future operations and guarantee programme sustainability;
- adequate and flexible autonomy at a local level with regard to strategies, decisions, supplies and equipment, together with a centralized mechanism for overall planning and guidance;
- development and application of policies.

The following specific requirements for the management of vector control activities must also be met:

- The management must ensure a rapid response to existing malaria problems and to changes such as epidemics, the emergence of multidrug resistance in parasite populations and sudden changes or increasing trends in disease incidence or severity. Any such developments must be recognizable and pinpointed through the surveillance systems of health services and malaria control programmes, and interventions should be carried out primarily by malaria control personnel.
- Support must be made available to communities for the implementation of personal-protection and other community-based control measures.
- Motivation and support are needed for community and multisectoral actions to reduce environmental risks created during development and other human activities and under poor living conditions.
- Emphasis should be placed on selective vector control founded on methods and strategies chosen on the basis of specific epidemiological, entomological and operational criteria.

Currently, vector control activities in Category II countries are the responsibility of specialized malaria control programmes or comprehensive vector-borne disease control programmes, some of which are fully or partially integrated with general health services and primary health care programmes, whereas in Category I countries, programmes have limited infrastructure and little or no previous experience in vector control. The management processes of all these programmes must be oriented to accommodate the demands for selective vector control.

12.1.1 *Category I countries*

In the Category I countries, the managerial requirements and processes will depend not only on the vector control strategies envisaged but also on the information available locally from the health system or from other sources such as research institutes, and the existing expertise at national level. Most of the experts may need to be recruited from universities, research institutes or the agricultural sector and will work with the vector control programme on a collaborative basis.

The management system must ensure logistic support for vector control. For example, it should facilitate the supply of insecticides, nets and other materials and provide continuous support for the treatment and re-treatment of materials and for their distribution. It should make provision for the collection and dissemination of information and should monitor operations and their effectiveness. Management should also meet the requirements for entomological support and vector control in relation to the prevention and control of epidemics.

12.1.2 *Category II countries*

Major adjustments are needed to the existing managerial structures in many of the Category II countries to meet the requirements of selective vector control that relies on methods that are chosen on the basis of specific epidemiological, entomological and operational criteria and that may have to be applied at different times in different areas.

The existing structures of most programmes involve procedures which may have been designed to deliver a single control strategy often on a blanket coverage basis. The programmes may already have considerable centralized expertise in logistics but there will be a need to evaluate alternative methods of vector control and to consider targeting them, or those currently being used, towards specific geographical areas and high-risk groups.

Selective vector control will require more comprehensive data management systems than have been used to date, using data from a wider range of sources within and outside health services; it will also require additional analytical skills. The managerial process will be much more demanding both technically and operationally.

The Study Group made the following recommendations for Category II countries:

- A national, centralized unit (vector control unit or advisory committee) should be formed to represent entomological, epidemiological, public health engineering and health education expertise. This body must be competent, and should guide overall programme activities for vector control; its possible functions are outlined in Annex 3.
- Decentralized expertise and support at the intermediate level should be ensured to permit implementation and monitoring of vector control strategies, and prompt detection of, and response to, local needs and epidemics. The operational structure of management at intermediate level and its interaction with central and peripheral units are outlined in Annex 4.
- A national task force for malaria control should be established to interact with relevant ministries and sectors concerned with malaria control to ensure the development and implementation of consistent policies on vector control and disease prevention and to promote intersectoral collaboration. The national vector control unit should be represented in the task force.

These units and activities should be accommodated within the national institutional structures for malaria control.

Vector control and entomological staff at the peripheral level are responsible for the implementation of vector control, e.g. house-spraying, insecticide-treatment of fabrics and their distribution (or helping communities to carry out these activities themselves), identifying and demarcating breeding sites and carrying out larval control. These personnel should also promote and emphasize the importance of community involvement. They should communicate the importance of vector control to the community and make members aware of the control plans and schedules, encourage participation in health education and help supervise community-based vector control activities. In addition, they should report on field activities to the intermediate level, and maintain contact with higher-level decision-makers to facilitate rapid disease assessments and the formulation of intervention plans. The peripheral level should be the first to recognize and alert the higher levels to possible epidemic-precipitating factors and to emerging risks and epidemics.

The staff at the peripheral level may be permanent or temporary (community volunteers, hired personnel or multifunctional workers shared by other departments of the health services). They should be directly supervised by higher-ranking staff at the peripheral level itself and less frequently by staff from the intermediate or central levels.

12.2 Management of the entomological component of vector control

12.2.1 *Category I countries*

The entomological component of vector control may not be appropriately developed or utilized in Category I countries. The routine monitoring of relevant entomological indicators is best done by personnel within the health services as these indicators need to be analysed in relation to their impact on disease. The Study Group therefore recommended that entomological services be eventually developed within malaria or vector control programmes. In the meantime, disease control programmes may request technical expertise from universities or research institutes for special surveys to support the development and planning of appropriate strategies, to provide high-level entomological support and training, and to meet the requirements for dealing with epidemic risks and epidemics.

12.2.2 *Category II countries*

In most Category II countries high-level entomological expertise already exists. However, the demands of selective vector control upon entomological services are greater than those of an approach that uses a single intervention. Appropriate entomological expertise and other resources will be needed as integral components of vector control management at each level. The resources should include transport and laboratory facilities to permit the collection of information required for planning and evaluating different strategies and for training district and local staff.

Monitoring of entomological indicators and supervision of vector control activities are needed at the district level. The resources required at this level include entomological laboratory facilities to enable staff to respond to immediate needs without having to await central-level decisions. Personnel at the peripheral level will carry out routine operational monitoring of the indicators specified in Table 1, page 34, in collaboration with, and under guidance from, the district and central levels.

Information exchange and active interaction between all levels of entomological expertise and vector control operational staff will ensure that plans made at the central level are appropriately implemented, and that changes in any indicator that may threaten the chosen strategies are brought rapidly to the attention of the decision-makers.

13. Comprehensive vector-borne disease control

It is necessary to differentiate between integrated vector control, selective vector control, and comprehensive vector-borne disease control. Integrated vector control implies the use – whether selective or not – of more than one vector control method, applied simultaneously or consecutively in a given area, to control one or more vector-borne diseases. Selective vector control is the *selective* use of one or more of the available control methods, the decision-makers having taken into account:

- the disease status and risks in order to decide on the needs and priorities for vector control;
- the vector, human behaviour and the environment in order to determine which control methods are suitable and where they are needed;
- the resources available to implement action.

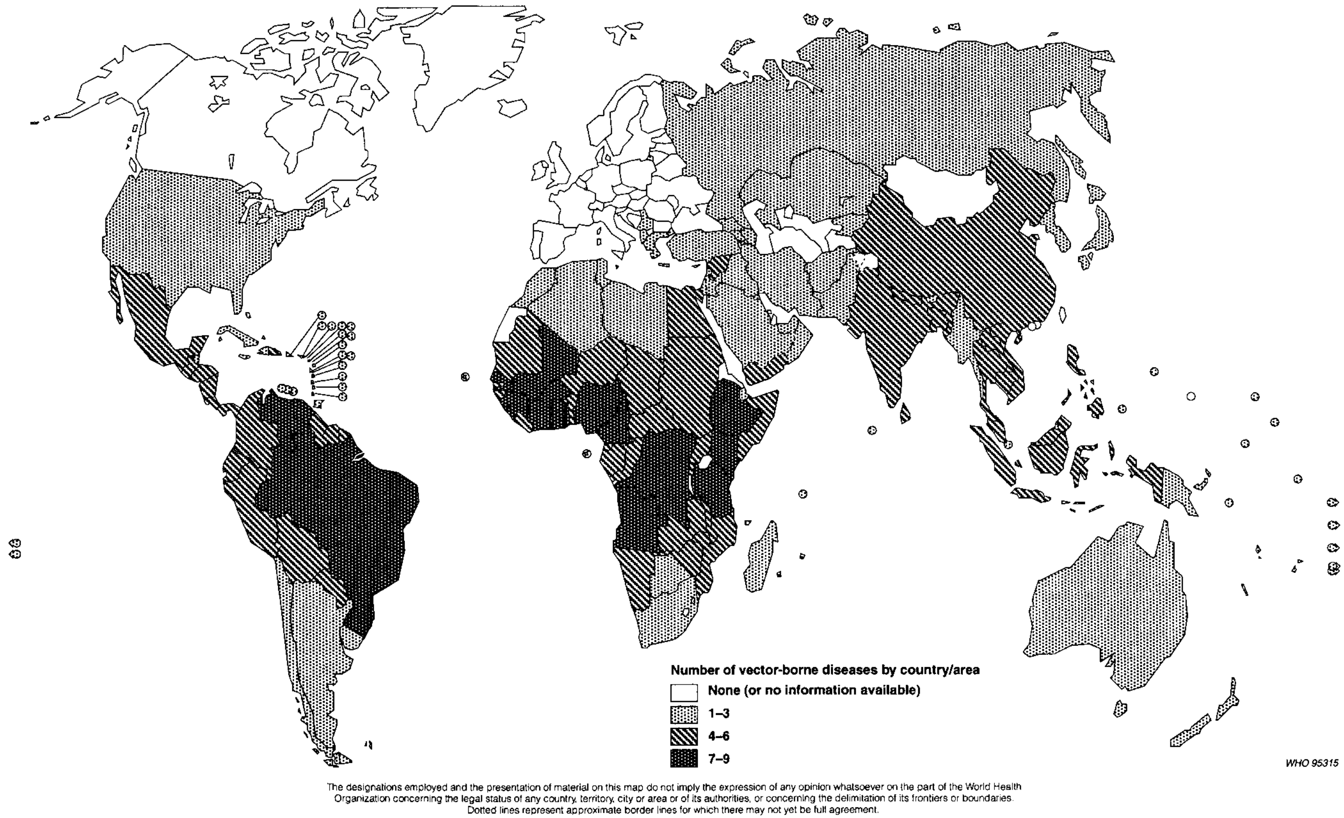
The term "comprehensive vector-borne disease control" refers to the control of a number of vector-borne diseases through a unified managerial structure.

Vector-borne diseases such as malaria, filariasis, dengue, dengue haemorrhagic fever, Japanese encephalitis, yellow fever, visceral leishmaniasis (kala-azar) and African trypanosomiasis are on the increase in certain countries. In most tropical countries, more than one vector-borne disease presents a public health problem (Fig. 2 and Annex 5). A well designed comprehensive approach through a unified managerial structure is desirable, instead of specialized vertical structures for the control of each disease. This can enable available national resources for both curative and vector control services to be shared or pooled in order to deal with a number of vector-borne disease problems in a cost-effective and sustainable manner.

13.1 Technical and operational aspects

When different diseases and their vectors occur in the same ecosystems and the vectors have similar behavioural characteristics, specific interventions can be effective against several diseases at once. Cross-

Figure 2
Global distribution of vector-borne diseases, as reported to WHO[a]



[a] For a detailed listing by disease, see Annex 5.

benefits are not always observed since the distribution of most vector-borne diseases is focal and disease occurrences are sometimes epidemic. However, other vector-borne diseases often do occur in the same geographical or operational areas of a country as malaria. For example, *An. stephensi*-transmitted malaria, lymphatic filariasis transmitted by *Culex* spp. and dengue and dengue haemorrhagic fever transmitted by *Aedes* spp. occur together in certain urban areas, such as Madras and Bombay in India. Malaria and kala-azar coexist in some areas of Bangladesh and India, and the distributions of malaria, Japanese encephalitis and brugian filariasis overlap in many rural areas in Asia.

Diseases that coexist in the same areas may or may not be controllable by the same interventions. The vector species may differ in behaviour, seasonality or habitat preferences. However, in local situations where several endophilic and endophagic vectors occur together and biting activities or breeding sites are similar, control measures can be effective against several vector species at once, as has been shown for malaria, leishmaniasis and Chagas disease vectors. Certain vectors of malaria and Japanese encephalitis breed in the same rice agroecosystem and might also be accessible to control by a common method.

When specific environmental risk factors influence the transmission potential of a number of disease vectors, appropriate environment-based interventions can help to prevent and control several vector-borne diseases simultaneously.

13.2 Managerial requirements

Malaria control is generally a priority in the countries in which it is endemic and malaria control programmes often have the most developed infrastructures and resources. These resources are often also utilized to deal with outbreaks of dengue, dengue haemorrhagic fever and Japanese encephalitis. With few exceptions, these are ad hoc arrangements and are not based on predetermined managerial structure or planning. The indirect benefits of malaria control for the control of other vector-borne diseases have been mainly incidental.

In theory, a comprehensive approach that incorporates selective intervention and effective planning can economize on national resources, maximize overall impact and strengthen the primary health care system. Technical competence, managerial skills and the flexibility to deal with the multifaceted challenges of vector control and associated environmental issues are critical for comprehensive vector-borne disease control. Programme management demands a sound understanding of the vectors, the ability to predict and react to the social and economic consequences of control actions and to changes in environmental risks and an ability to accommodate to local differences in health activities. A sound managerial and operational structure is needed at the national, intermediate and peripheral levels for all aspects of vector-borne disease control. The managerial structures envisaged are comparable to those described in section 12 for malaria, and in many cases the infrastructures and resources of the existing malaria control programme can serve as a basis on which to develop a comprehensive control programme.

13.3 Role of entomology

Entomologists employed in public health programmes (medical or public health entomologists) are the most appropriate human resource to deal with epidemiological aspects of vector-borne disease transmission and with the broader environmental issues involved in transmission risks. The role of these entomologists therefore needs to be broader and more comprehensive than it is at present. This calls for changes in structure, planning, job descriptions, qualifications and training. In general, qualifications at the level of MSc or PhD are essential for the performance of the expected duties; but the skills acquired during the process of obtaining the qualification or during subsequent training must be relevant to vector control if the entomologists are to deal effectively with the local disease problems.

Such personnel will meet the requirements of the Global Malaria Control Strategy and be able to support comprehensive vector-borne disease control as well as implementation of the WHO Global Strategy for Health and Environment (*12*).

14. Capacity building

The implementation of any of the strategies discussed in the previous sections of this report will not be possible without the capacity and the resources to put plans into action.

Resources are limited in countries in which malaria is endemic. Development aid needed for capacity building has recently been reduced. The number of countries and populations dependent upon, and competing for, resources has increased considerably. This is particularly true of resources for control of vector-borne diseases, and for long-term preventive rather than curative health services. These resource constraints oblige the designers of health programmes, including those for vector control, to examine their strategies carefully, to determine the order of priority of health issues, and to make the best use of available resources.

The planning and implementation of vector control require the creation or modification of infrastructure, managerial expertise, financial resources, access to information and capacity for data and information management and for training. Human and material resources are equally important as one cannot function without the other. This section of the report focuses on issues relevant to human resources.

Implementation of the Global Malaria Control Strategy requires the development of local capacity for selective vector control. This may involve (re)training and (re)orientation of both new and existing control programme staff. The immediate training needs and priorities will vary between countries in Categories I and II.

There is generally an acute shortage of trained personnel capable of analysing and managing environmental, epidemiological and entomological risk factors, and for short-term and long-term planning. There is a need for entomological staff with broader epidemiological expertise and skills in information and data management and community and intersectoral mobilization. Vector control and entomological staff should be able to identify needs for problem-solving research, assess priorities, implement selective vector control and translate research findings into action. Training skills are also needed.

There is also a need for the development of comprehensive and integrated approaches to vector-borne disease control where more than one vector-borne disease poses a public health problem.

Mechanisms and opportunities are needed to develop the required capacities. Examples of areas of action are:

Curriculum development and modification

- modifying existing training curricula in medical entomology, malaria and vector-borne disease control to cover the needs of selective vector control;
- incorporating aspects of disease transmission, entomology and the environment, needs for vector control and possible interventions into the curricula of science, medical and engineering faculties;
- incorporating teaching about vector-borne diseases, transmission risks and vector control into the health curricula of primary and secondary schools;

Individual and group training and career development

- encouraging trainees on undergraduate and postgraduate courses to carry out fieldwork in areas relevant to the most important research issues in their own country (or in another country with related problems) so that applied field skills and problem-solving skills can be acquired and the results of the research are applicable to control programmes;
- provision of task-oriented training at all levels;
- support for group training in the concepts of stratification (see section 6.4.2) and selective vector control, the role of vector control in primary health care, management skills, data management and analysis, and community and intersectoral mobilization;
- developing the training skills of national-level trainers;
- meeting requirements for training in specialized techniques, where relevant;

- providing opportunities for staff, especially those at central level, to obtain higher qualifications to facilitate interaction at national policy-making and decision-making levels and with other sectors;
- developing a career structure for entomological staff to encourage trained, competent and skilled staff to remain in the vector control programme;

Development of training facilities and infrastructure

- developing and strengthening regional training programmes to meet the requirements of the Global Malaria Control Strategy;
- developing intercountry and interregional networks for exchanging information and expertise in entomology, epidemiology and other aspects of vector control and malaria control;
- promoting links between centres of excellence and links for support of training and transfer of technology;
- exploiting new technologies in training (e.g. through WHO's MANTEAU project, a collaborative venture whose goal is sustainable tropical diseases management linking science, technology and training) and the research and training facilities of the UNDP/World Bank/WHO Special Programme for Research and Training in Tropical Diseases.

15. The role of communities and other sectors in vector control

All of the vector control options outlined in section 7 of this report depend upon the supportive actions of individuals and communities for their long-term use and sustainability:

- The sharing and pooling of resources through intersectoral collaboration, avoiding duplication of activities and waste, can contribute to better delivery of services, cost-effectiveness and sustainability.
- Many agencies promote or support malaria control at different levels within a country. Their activities are not always related to the requirements, objectives and strategies of the national control programme. The separate actions of these agencies can lead to a waste of resources and disparities and conflicts in services, which are not conducive to cost-effectiveness or sustainability. Coordinated actions directed towards common goals and objectives help in the optimal use of resources.
- Many activities of the community and of various agencies that are intended to improve living standards inadvertently increase the risk of malaria and other arthropod-borne diseases. Coordinated actions could prevent or reduce the negative consequences – vector-breeding potential, human-vector contact and disease transmission.

15.1 Community involvement

There is no universally applicable model for community involvement. Involvement is a dynamic process that eventually depends upon local understanding and acceptance of the importance of controlling the disease(s) in question. Fig. 3 provides an overview of some of the requirements for community acceptance of a vector-borne disease programme, and some of the major issues in community mobilization are summarized below.

15.1.1 *Existing community structures*

In many areas, e.g. the Amazon and multidrug-resistant border areas of Thailand, where the individual risk of malaria is high, the individuals at risk do not form part of a stable, coherent community. In these circumstances, the mass effect of vector control options such as residual house-spraying and use of impregnated bednets, which depend upon stable community structures and involvement (as well as endophilic vectors), will not accrue. Individual options (use of repellents and bednets) will reduce individual risk, but will probably not have a great effect on community risk.

Where there is a stable community, its infrastructure should be utilized. For example, where a good social infrastructure (schools, clinics and primary health care systems, agricultural networks and voluntary organizations) exists, vector control, along with other aspects of malaria control such as early case-detection and referral, can be organized through the infrastructure, with costs and technical aspects subsidized by the vector control programmes.

15.1.2 *Knowledge and skills*

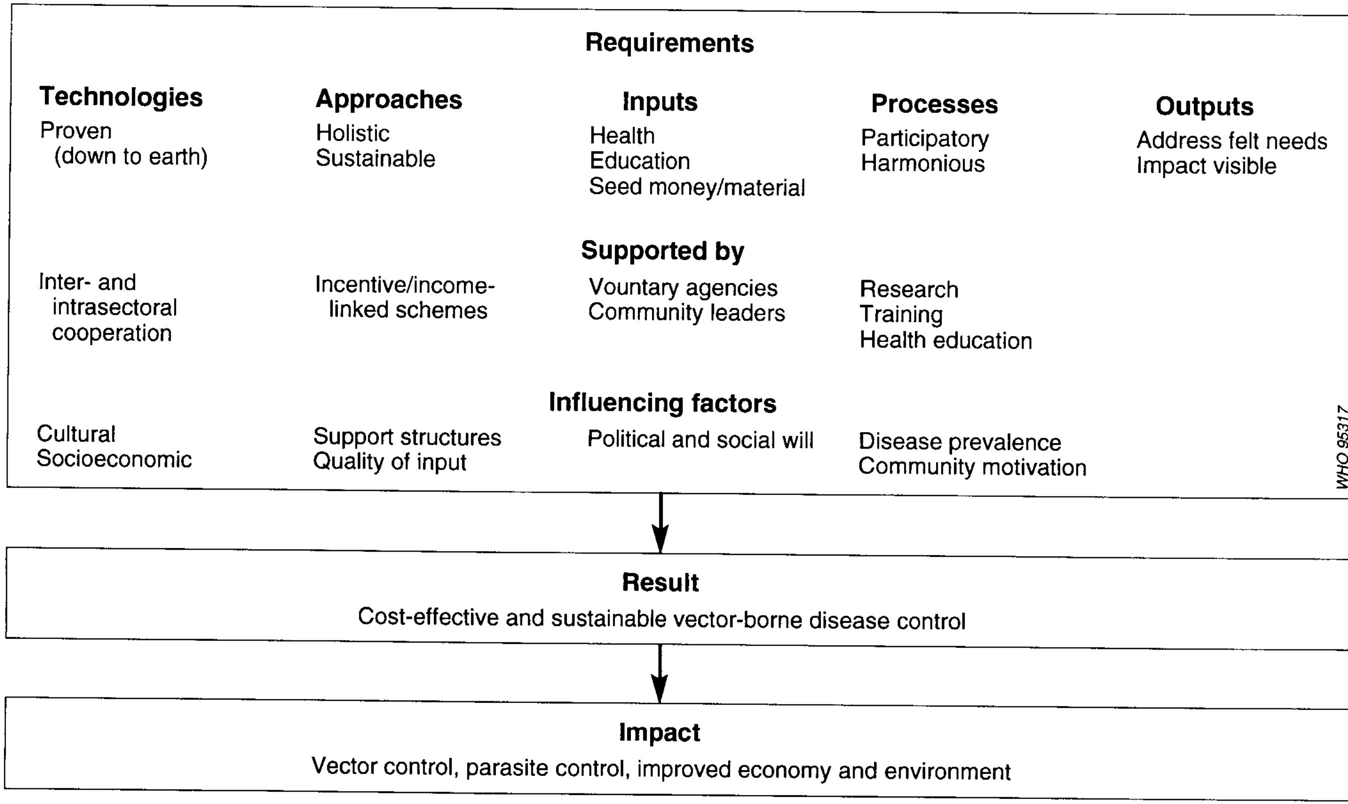
Local community members should be provided with information on where and how the mosquitos breed, rest, bite and transmit malaria and on potential interventions. They should also be taught the skills needed to assist in or undertake vector control, e.g. treatment of bednets, residual house-spraying and environmental management.

Communities can assist in the insecticide-spraying of houses in several ways, for example by providing water to prepare the insecticide suspensions/emulsions, storage facilities for insecticides, and advance notification of the vector control schedules to other members of the target communities, and by helping to prepare houses for spraying. Communities can ensure the use of the correct quantities of insecticides in insecticide suspensions/emulsions and can also prevent insecticides intended for house-spraying being used on agricultural land.

15.1.3 *Local political support*

Experiences of successful community-based vector control in a number of countries (Boxes 11 and 12) have demonstrated the importance of

Figure 3
Requirements for sustainable community participation in vector-borne disease control[a]



[a] Adapted, by permission, from reference *3*.

close interaction of the vector control staff with local leaders and community members from the planning stage to the management of malaria control activities, taking into account the perceptions, beliefs and cultural habits of the people. Well defined roles and responsibilities for the communities are also important, as are good leadership and appropriate policies to support and promote community participation, including the contribution of material resources.

15.2 Intersectoral collaboration

Intersectoral collaboration in vector control should be aimed at coordinating activities so as to ensure consistency of effort, elimination of duplication of work and sensible utilization of resources.

Box 11

Examples of community participation: Asia

A nationwide Patriotic Hygiene Movement organized in China by the Chinese Government in the 1950s and 1960s aimed to eradicate four target pests (mosquitos, houseflies, snails and rodents) and helped to control schistosomiasis and filariasis. The movement now focuses on incentive-linked community vector control with the benefits of simultaneous rearing of larvivorous and edible fish in rice fields. These activities have reduced the populations of mosquito larvae, and the increased crop yield has resulted in a substantial increase in the earnings per unit area of rice field.

Communities in India have been involved in many activities to reduce mosquito breeding. These have included infilling of unwanted water bodies and low-lying waterlogged areas, planting eucalyptus trees to dry up marshy areas, converting waste land to plantations, improving drainage and breeding larvivorous fish together with edible fish. Communities have also undertaken insecticide-treatment of bednets and have monitored their use and maintenance. Some activities have had permanent benefits or have provided income-generating opportunities. In Pondicherry and in Kerala State, improvement of drains by communities has led to the control of *Culex quinquefasciatus*, and the removal of weeds from water bodies to the control of *Mansonia* spp. mosquitos.

In a periurban area in Malaysia, community leaders have established committees that provide education on source reduction for dengue control on a house-to-house basis. In rural villages, committees that organize various socioeconomic activities act as foci for sustained community participation in health-related activities, with limited support from the health services. On a smaller scale, through a system established to involve households in groups of 10, members of families have been encouraged to identify their health care needs and take appropriate action. This system is considered a suitable entry point at which to introduce the use of insecticide-treated bednets in the malarious areas, and to promote other simple and practical interventions including environmental management.

Box 12

Examples of community involvement: Africa

In Madagascar, communities transport insecticides and spraying equipment in the field, and village health workers (*aides sanitaires*) in charge of public health centres play a decisive role in sensitizing the population in support of house-spraying. In Ethiopia, community members (associations of farmers, urban dwellers, young people and women, and trade unions) work as spraying personnel, porters and control programme coordinators, and provide DDT storage facilities.

In Kenya, a specific managerial structure based on the Bamako Initiative has shown the importance of a sense of community ownership and of the community having direct control over financial resources and decision-making. Mosquito nets and insecticides for their treatment are among the essential items paid for through a community-managed revolving fund.

Resources and information sharing

Other sectors may support malaria control activities by sharing costs. For example, personnel or equipment may be loaned for limited periods and the costs of supplies and training shared; information can also be shared.

Capacity building

Collaboration with ministries of education, universities and adult educational programmes can ensure that vector control is given due consideration in curricula and educational activities.

Policies, legislation and standards

Intersectoral collaboration is required for the development of, and adherence to, policies and legislation that facilitate the implementation and ensure the effectiveness of many vector control approaches. Policies or legislation may be needed to govern the importation and use of pesticides to minimize the likelihood of resistance developing or to ensure quality, to guard against the creation of mosquito breeding sites and malaria transmission potential during development activities, and to promote better housing in planned settlements.

Links in the public sector

Links are essential between the ministries of health responsible for vector control programmes and the other relevant ministries or bodies involved in development projects. Intersectoral communication should ensure that health personnel have advance notice of activities planned by other sectors that are likely to influence malaria or vector-related problems, and allow the necessary action to be taken to prevent or minimize potential ill-effects.

Vector control interventions involving other sectors

Certain vector control methods, e.g. water management, intermittent irrigation and specific agricultural practices, need interaction between the health services and other relevant sectors, both for determining the relevance and feasibility of the proposed methods and for promoting their subsequent sustained application, backed up by monitoring and evaluation. Some of these activities may involve operational research.

16. Cost-effectiveness in vector control

Malaria control is a continuous activity with important capital and recurrent costs that demand regular allocations from the health sector budget. When financial resources are limited, the most cost-effective mix of options for disease control, including different vector control methods, needs to be determined.

The decision to invest scarce public resources requires information about the likely or measured effects of the interventions (which is difficult to obtain for preventive measures) and whether the resources would be better used elsewhere or for other purposes.

There are two types of costs in disease control programmes. The first type are those incurred in the planning, implementation, monitoring and evaluation of the programmes themselves by the public sector (health services) and the private sector (including expenditures at the household level). These costs are expressed in monetary terms. The second type of costs are those that result from ill-health in areas where health services cannot provide sufficient or consistent preventive or protective measures; such costs are difficult to express in monetary terms. Of the various comparative evaluation methods, i.e. cost-effectiveness analysis, cost-benefit analysis and cost-utility analysis, the first is the most appropriate for malaria control.

A detailed, step-by-step account of the analysis of the cost-effectiveness of vector control is presented by Phillips, Mills & Dye (*8*). A periodic assessment is needed of the cost-effectiveness of individual control options, and of the vector control programme as a whole under changing conditions. A realistic analysis should include consideration of the opportunity costs of contributions made through community participation and the inputs of other, voluntary groups.

The cost-effectiveness of malaria control programmes can be substantially enhanced by:

- sharing of resources within the health sector as well as with other sectors;
- economies of scale achieved through a single management structure for the control of several vector-borne diseases;

- using incentives (e.g. economic) to elicit the cooperation of community members in the implementation of vector control measures.

It is often easier to identify the factors that reduce the efficiency of an intervention (such as a spraying programme) than to describe the conditions under which such an intervention is the most cost-effective option and should be undertaken. The right choice of effectiveness indicators together with a solid knowledge of vectors and epidemiology are crucial for choosing the right option. For example, residual spraying has sometimes been carried out in areas where the vector is exophilic and exophagic, or where vector resistance has not been taken into account in the decision on which insecticide to use. The incidence of infection and the associated levels of morbidity may vary significantly from one village to another, so that mass spraying of all the villages in a region or area according to an average annual parasite incidence can lead to considerable waste. In certain countries, spraying of cattle sheds apparently has little impact on transmission, yet it consumes considerable resources. These examples suggest that, by careful targeting, the costs of existing vector control programmes can be lowered with no reduction of effectiveness. Such an approach reduced the recurrent costs of a control programme in central Java by 24%. Spraying during peak transmission periods instead of perennial spraying can also reduce costs without affecting impact.

In estimating the cost and effectiveness of vector control, the calculation of the cost component is relatively straightforward if reliable data are available. For measuring effectiveness, the choice of appropriate indicators is essential. Once the chain of effects of each vector control option has been defined, the first point in the chain where the effects of different options coincide must be determined. The greater the disparity between the methods compared, the further along the chain of effects will a common indicator be found. As a result, effectiveness is often measured using epidemiological parameters. But, the further down the chain of effects the indicator is located, the more room there is for confounding factors. It is therefore important to ensure that entomological parameters, which provide information on effects earlier in the chain, are also considered when the effectiveness of vector control activities is being assessed.

In many countries there are insufficient reliable data available to provide a sound basis for cost-effectiveness studies, and this situation is unlikely to change in the near future. In the interim, vector control options may be evaluated on the basis of financial cost, qualitative benefits, workability and sustainability. It is important that methods for rapid assessment of epidemiological, entomological and socioeconomic parameters be further developed and improved, so that they can be effectively applied to cost-effectiveness analysis. At the same time there is a need for local capacity building for improved decision-making through the development of criteria and practices based on the limited data that are available from rapid assessments.

Control programmes should ensure careful and systematic documentation of resources utilized, data on disease outcome and other indicators, so that reliable data are collected over time for a critical review of the cost-effectiveness of interventions. Where more than one intervention is used, indicators need to be carefully selected to allow assessment of the contribution of each intervention to overall effectiveness. This is particularly important in the context of selective vector control where different vector control methods with widely varying characteristics (with regard to costs, efficacy, etc.) need to be used.

17. Research in vector control

Problem-solving research that has direct relevance to vector control is an essential component of any operational programme. Such research aims at increasing the operational impact of control interventions. This entails making optimal use of the tools that are currently available and evaluating the relevance of new methods under local circumstances.

Basic research is not normally an integral part of a control programme but it is relevant to improving malaria control. Examples of basic research that would yield results of immediate relevance to control programmes are: the development of new or improved field techniques and managerial tools; and the identification of ecological and entomological characteristics that can be used to define risks.

17.1 Research objectives

The objectives of vector control research for malaria control are therefore:

- to examine the relevance of selected vector control methods to local situations;
- to develop or improve field techniques and assess the relevance of currently used indicators;
- to develop entomological indicators of disease risks and epidemics, so that people can be alerted and an early response made;
- to develop innovative vector control techniques and approaches for the control of malaria and other vector-borne diseases.

Some of the research priorities related to implementation of the Global Malaria Control Strategy are listed in Annex 6. While most are relevant at local level, some are also important at the regional and global levels.

17.2 Research promotion and utilization of research findings

Both basic and applied research into many aspects of vector control is needed to improve the control of malaria. However, it is neither practical nor feasible for malaria control programme personnel to undertake all such research on their own, as they generally lack resources, time, and the necessary training, skills and experience to do this. On the other hand, research could be undertaken, and the research capacities of control programme personnel enhanced, through collaborative work between control programme scientists and members of research institutes. This would permit sharing of national resources (both human and logistic) and information and the development of research proposals relevant to local needs that might be considered for funding; it could therefore be both productive and cost-effective.

Some of the requirements for the promotion and support of research are listed below:

- Operational research priorities should be established. The staff of malaria control programmes should draw particular attention to the specific issues, problems and concerns (based on local field experiences) that may warrant specific research and should help to establish priorities for research.
- The resource needs of each research partner should be identified for every specified area of research, and support sought where relevant.
- Research findings, conclusions and experiences (successes and failures) should be documented, and the information disseminated to control programmes and supporters of research. This can be done through document distribution or through workshops and seminars. When the application of research findings necessitates decision-making and support at the macroeconomic level, the findings must be appropriately and convincingly communicated to the relevant authorities (e.g. those responsible for finance, policies, legislation or administration). The national task force, the central core group of the malaria control programme and key researchers can play a leading role in highlighting the relevance and benefits of research findings and their application to any proposed activity.
- Findings should be extrapolated to comparable situations at national, regional and global levels.

18. Policy issues related to vector control

In general, vector control programmes operate within the policy framework of the health sector or municipalities. However, the policies of other sectors, and national economic and development policies, can directly influence the effectiveness of vector control activities or indirectly affect the vector-borne disease situation and hence the demands on vector control programmes.

18.1 Health sector policies

In countries where policies for malaria vector control still reflect objectives and approaches from the eradication era, policies need to be reviewed and adjusted to reflect the requirements of the Global Malaria Control Strategy. A key issue in policy modification is the integration of malaria control into the general health services, with provision for a vector control component, staffed by well qualified entomologists and other relevant personnel, that can function effectively within this structure.

The decisions made about vector control operations should be guided by policies that emphasize the requirement for cost-effectiveness in the selection of control options, which may imply integration of control activities aimed at the vectors of different diseases. The promotion of selective vector control adapted to local conditions, with special emphasis on the rational use of insecticides, should be an explicit policy of health ministries. Policies should specify decision-making criteria for intensified action in anticipation of disease outbreaks. It is also important that attention is paid to the need to prevent or delay the appearance of insecticide resistance as a result of excessive or improper use of insecticides. This may require interministerial and interdepartmental policies involving, for example, the collaboration of ministries of health and agriculture and municipalities.

In collaboration with the ministry of finance, the ministry of health should develop fiscal policies to promote effective community involvement in the planning and operation of vector control. In addition, mechanisms should be introduced to facilitate the procurement of consumables for malaria control (e.g. exemption from payment of duty) and to stimulate their local production whenever feasible.

The health sector should play an active role in the formulation of policies relevant to land and water resources development (see also section 18.2). Planning should include an assessment of the likely impact on health to ensure that projects incorporate safeguards against conditions that exacerbate mosquito breeding and disease transmission potential. When bilateral or multilateral assistance is offered, adequate funding for such impact assessments should be requested. In policies for staff training, health ministries should indicate the need to improve the capacity of health personnel to participate in intersectoral planning and activities.

In countries undergoing rapid urbanization, national health authorities should encourage local government and municipal health authorities, who are generally responsible for urban vector control, to adopt appropriate policies on intersectoral issues that influence the transmission of vector-borne diseases.

In view of the need for rapid and effective responses to epidemic situations (particularly those complicated by multidrug resistance) in border areas and refugee camps, policies initiated by ministries of health are required to expedite international collaboration and action.

18.2 Development policies

Water policies

Good-quality water resources are becoming scarce in many parts of the world and the governments concerned are formulating policies aimed at conserving water, and ensuring a balanced allocation to user groups (for drinking-water, agriculture and industry). The Food and Agriculture Organization of the United Nations promotes national policy formulation as part of its programme of water management for sustainable agricultural development. The health sector should draw attention to water-associated health issues, emphasizing the importance of developing, and adhering to, appropriate policies for the prevention and control of malaria and other vector-borne diseases.

Agricultural policies

Agricultural policies relating to irrigation development and management, pesticide use, land tenure and use, and research have a potential impact on human health. Health ministries should examine these policies and recommend adjustments where appropriate.

Environmental impact assessment policies

Most external agencies supporting development projects have policies requiring an assessment of environmental impact. Many developing countries are formulating similar national policies, linked to building of capacity to make such assessments. The health sector should ensure that health impact is included in environmental impact assessments and that project design incorporates health safeguards, with provision for any necessary strengthening of health services.

Research policies

In the wake of the 1992 United Nations Conference on Environment and Development, and the adoption of Agenda 21, research policies have shifted towards the promotion of multidisciplinary, problem-oriented studies. This opportunity should be harnessed in support of vector control research that requires multisectoral action and community involvement.

19. Conclusions and recommendations

Use of existing vector control methods

1. The existing vector control tools have been, and still can be, effective in reducing or interrupting transmission and thus preventing malaria. However, they must be selectively deployed if vector control is to be cost-effective and sustainable.

Long-term impact and sustainability

2. In the long term, the impact of any vector control measure, including indoor residual spraying, personal protection or environmental management, depends on the importance given to the measure by the communities at risk and on their understanding of and involvement in its application. In addition, the sustainability of any vector control activity depends upon its affordability, acceptance and effective use.

Selective vector control

3. All vector control methods should be selectively deployed with foreknowledge of vector behaviour and the likely impact of the control method on the vector population and the target disease. Priorities for selective vector control should be set according to needs and resources.

Expertise in vector biology and ecology

4. Successful vector control requires sound knowledge of vector biology and ecology. It is therefore recommended that entomological activities be supported within malaria control programmes to evaluate the relevance of different vector control methods and strategies, and to plan their geographical coverage. Monitoring the effectiveness of the chosen methods of vector control should ensure proper implementation and an appropriate outcome, i.e. a decline in vector population, malaria and malaria risk.

Indoor residual insecticide-spraying

5. Indoor residual insecticide-spraying can be an integral part of malaria control but must be used very selectively. It must be confined to high-risk situations and is relevant when applied selectively in areas where endophilic vector populations are involved in transmission, where the majority of house structures have surfaces appropriate for spraying and where it is well accepted by the population. Changes in vector behaviour and the development of physiological resistance may limit the long-term use of this strategy.

Insecticide-treated material

6. Insecticide-treated bednets, curtains and hammocks can be important components of vector control. However, their impact depends on the degree of endophagy of the vector population, whether the peak biting times of vectors correspond with the sleeping patterns of the human population, the proportion of households using the materials, the quality, efficacy and residual effect of the insecticide, and mosquito biting behaviour; moreover, repellents may need to be used on skin or clothing to prevent biting when people are not protected by the insecticide-treated materials. Insecticide-treated bednets have been

shown to be effective in certain situations and are already in operational use in some countries. However, further evaluations are needed to clarify their value in diverse epidemiological situations and in relation to other methods. The results will need to be taken into consideration where replacement of house-spraying with treated bednets is contemplated.

Use of synthetic pyrethroids

7. Synthetic pyrethroids should not be used for indoor residual spraying in areas targeted for insecticide-treated bednet use if the development of physiological resistance is to be prevented or delayed. Their use as agricultural pesticides should be discouraged in situations where the selection of resistant malaria vectors is likely.

Larval control options

8. Larval control options include the use of larvicidal chemicals, biocides, biological agents, environmental management and physical barriers (polystyrene beads or oil on water surfaces). Larval control is most relevant in urban and arid areas, during dry periods in restricted rural areas, and where breeding sites can be clearly defined. Monitoring should ensure that the agent chosen is effective, that adult populations are suppressed and that financial resources are effectively utilized.

Environmental management

9. Environmental management should be given priority as a method of vector control wherever it is economical, operationally feasible and scientifically relevant.

Development projects

10. Development projects or activities that change the ecology of an area and involve population movements should always be considered in terms of their potential to increase vector breeding sites, human-vector contact and the risk of disease transmission. Preventive safeguards should be incorporated at the planning and implementation phases.

Multidrug resistance

11. Multidrug resistance of parasites to the limited number of antimalarial drugs is a major obstacle to malaria control; areas in which such resistance occurs should therefore be a priority for vector control. All possible efforts are needed in these areas to reduce the size of the parasite reservoir and block transmission by properly targeted vector control.

Data management

12. Proper collection and management of data are essential for efficient planning and implementation of vector control, for distinguishing the effects of vector control from chance variability and for recognizing operational problems. Precise data are critical because of the possible short-term variation in malaria prevalence and the need to be able to replicate successful vector control measures. Information systems and networks operating within and between countries and regions, including border areas with specific problems, will allow for better exchange of information and rapid interventions. Computerized databases with geographical information systems will allow rapid access to information and can serve as management tools. Data from remote sensing, where possible, could support the predictive function of databases.

Monitoring of indicators

13. Monitoring and evaluation of operational, entomological and disease impact indicators are essential, and must include comparative assessments of different vector control methods when used alone or in combination. Monitoring and evaluation are needed before the introduction of interventions and during their operational use.

Cost

14. All vector control activities entail a financial cost (including salaries, capital, supplies and transport), which must be regularly monitored, well documented and evaluated in relation to impact.

Programme management

15. Suitable managerial skills are needed to accommodate current trends in vector control, to reorient vector control programmes that were originally structured to meet requirements for malaria eradication, and to provide adequate support for programme implementation. Malaria control requires the decentralization of many aspects of vector control to promote effective management, timely intervention and maximum impact.

Local capacity

16. Local capacity, including human resources, is a prerequisite for the achievement of effective and sustainable vector control. It is therefore recommended that facilities for training and retraining middle-level and peripheral staff should be strengthened, with adequate support for the development of technical expertise at national level to ensure successful planning, guidance and implementation of vector control.

In this context, the Study Group also encourages the development and strengthening of training facilities at WHO regional level to meet the specific vector control requirements of each region.

Acceptability and participation

17. Community support and participation and intersectoral collaboration in vector control activities will influence the sustainability of operations at a satisfactory level of performance. Efforts to obtain such support will be essential in areas where the vector control strategy has been shown to be relevant and effective. Interaction between different disciplines and sectors should take place at all levels of planning, implementation and evaluation. Concerted activity to create community awareness and sensitivity and to provide the necessary training is essential.

Sustainability of operations

18. Vector control methods vary in terms of the sustainability of interventions (which depends on available resources, among other things) and in their impact. The latter may itself vary with the quality of operations, the epidemiological effects of sustained application of the vector control method and the availability of resources. These variations must be taken into consideration in the planning and implementation of vector control.

Operational research

19. Operational research should focus on problem-solving, leading to improved delivery and application of control methods. Such research should be encouraged and supported within the control programmes, and facilitated through collaboration with other control programmes and academic and research institutes.

Assessment of control programmes

20. Assessment of malaria control programmes should be undertaken regularly and must ensure that the requirements of the vector control component of the Global Malaria Control Strategy are appropriately met.

Malaria in border areas

21. The problems of border areas require intercountry and interregional collaboration to address issues of common concern, to exchange information and to facilitate coordination of activities for vector control (and other relevant aspects of malaria control).

Integration of vector control

22. Vector control and its entomological support services should be integral components of malaria control programmes within the general health services.

Insecticide registration

23. National registration authorities should not allow registration of pesticides for vector control without adequate evaluation data. Where there is no provision for national registration, the insecticide concerned should at least be registered elsewhere.

Urban and periurban malaria

24. The control of urban and periurban malaria is a priority in certain countries. In such situations the establishment and enforcement of legislation for community and intersectoral action, including source reduction, could be important for the control of malaria as well as dengue and lymphatic filariasis.

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[1] Unless otherwise stated, the people listed are at WHO headquarters, Geneva, Switzerland. CTD: Division of Control of Tropical Diseases; TDR: UNDP/World Bank/WHO Special Programme for Research and Training in Tropical Diseases.

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Annex 1
Use of DDT in vector control

The Study Group considered the current situation regarding the use of DDT for controlling vector-borne diseases, in particular malaria, in the light of two recent publications suggesting an association between DDT and human cancers (*1, 2*), a report on the presence of DDT in breast milk (*3*), and two general reviews of the subject.[1] Two expert toxicologists[2] were invited to review these papers, including the citations, and to participate in the discussions on DDT.

After careful review of the documents and intensive discussion, the Study Group concluded that:

1. The information presented does not provide convincing evidence of adverse effects of DDT exposure as a result of indoor residual spraying as carried out in malaria control activities.
2. There is therefore, at this stage, no justification on toxicological or epidemiological grounds for changing current policy (*4*) towards indoor spraying of DDT for vector-borne disease control.
3. DDT may therefore be used for vector control, provided that all the following conditions are met:
   (a) it is used only for indoor spraying;
   (b) it is effective;
   (c) the material is manufactured to the specifications issued by WHO (*5*);
   (d) the necessary safety precautions are taken in its use and disposal.
4. In considering whether to use DDT governments should take into account the following additional factors:
   (a) the costs involved in the use of insecticides (DDT or alternatives);
   (b) the role of insecticides in focal or selective vector control, as specified in the Global Malaria Control Strategy (*6, 7*);
   (c) the availability of alternative vector control methods, including alternative insecticides (in view of the availability of alternative insecticides for indoor residual spraying, some of which may compete with DDT in terms of epidemiological impact, public acceptability, logistic suitability and compliance with specifications issued by WHO, DDT no longer merits being considered the only insecticide of choice);

[1] Prepared by: Dr C.F. Curtis, Department of Medical Parasitology, London School of Hygiene and Tropical Medicine, London, England; and Professor J. Mouchet, French Institute for Cooperative Scientific Research for Development (ORSTOM), Paris, France.

[2] Dr W.N. Aldridge, The Robens' Institute, Kings Worthy, Hants, England; and Professor M. Lotti, Institute of Occupational Medicine, University of Padua, Padua, Italy.

(d) the implications for insecticide resistance, including possible cross-resistance to some alternative insecticides;
(e) the changing public attitude to pesticide use, including public health applications.

5. Given the paucity of data suggesting adverse effects of indoor house-spraying, further epidemiological investigation using rigorous scientific protocols is to be encouraged.

6. Further studies should also be carried out to:

   (a) examine the health effects of DDT in breast milk on breast-fed infants, including any resulting behavioural change;
   (b) investigate thoroughly any suspected association between the use of DDT in routine malaria control activities and an increased incidence of cancer(s);
   (c) clarify the significance of the reduction in muscarinic receptor density caused by DDT.

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Annex 2

Quick reference to actions recommended for the implementation of vector control

The Study Group recommended that all malarious countries take the following actions, progressively implementing vector control as they develop the information base, resources and infrastructure required. For the classification of countries into Categories I and II, see page 3 of the main report.

× Actions considered relevant to specific situations in many Category I countries; countries should first, however, assess their capacity to implement any planned activities.

■ Specific actions to be taken immediately in Category II countries, to meet the requirements of the Global Malaria Control Strategy.

\+ Actions needed in all countries, even in those with limited capabilities.

1. Information management

Consider as potential sources of information:

- health services +
- malaria control programmes ■ ×
- entomological services ■ ×
- other sectors, nongovernmental organizations, communities +
- research/academic institutes +
- research publications/documentation concerning experience of vector control, both local and in comparable situations in other countries. +

Collect, analyse and use information:

To assess the existing malaria problem:

- mortality, morbidity (including disease severity) +
- parasite species/rates by age, sex, month, village/area ■ ×
- drug resistance of parasites +
- current/emerging epidemics +
- areas, population groups, individuals most affected. ■ ×

To identify potential malaria risk situations:

- epidemic-prone areas +

- areas undergoing major ecological changes, development activities, urban/semiurban accretion +
- types of house, villages, populations and individuals at highest risk. ■ ×

On vector characteristics:

- incrimination of suspected vectors +
- role of vectors in different epidemiological situations and different seasons ■ ×
- vector behaviour in relation to control efforts and potential interventions +
- insecticide-susceptibility status. +

On the appropriateness of vector control methods in diverse epidemiological situations. +

Develop information collection and management systems. ×

Strengthen/reorient information management systems: ■

- ensure data collection forms are appropriate for strategy implementation ■
- restructure procedures and mechanisms for collection, transfer and use of information ■
- collect information systematically +
- computerize data management, and include geographical information systems. ■ ×

2. Development of capacity to predict epidemics

Identify epidemic-precipitating factors, including entomological and epidemiological factors +

Define the role of malaria control services, other sectors and communities in monitoring, alerting others to and responding to epidemic risks and epidemics +

Establish mechanisms for monitoring vector- and vector control-related factors that may precipitate epidemics and for reacting promptly to epidemic alerts +

Use resources at national, regional and global levels to enhance the capacity to predict epidemics. ■ ×

3. Stratification and priorities for vector control

Classify and confirm major ecotypes	+
Establish the relative contribution of different ecotypes to the malaria burden	■ ×
Begin "microlevel" analysis for selective interventions (e.g. at the level of villages or clusters of households)	■ ×
Set priorities in areas of major and immediate concern:	
– epidemics and areas at high risk of epidemics	+
– areas with high mortality and morbidity rates	■ ×
– areas with drug-resistance problems	■ ×
Select and use interventions on the basis of priorities or appropriateness	■ ×
Take action to:	
– reduce reliance on insecticides	■
– increase the use of personal protection and environmental management methods	+
– promote safeguards in development projects	+
– promote community and intersectoral action.	+

4. Management of vector control

Vector control delivery

Make use of health service facilities	+
Make use of primary health care networks	+
Obtain the support of nongovernmental organizations and communities	+
Establish infrastructures and mechanisms	×
(Re)orient institutional structures for centralized overall guidance of the programme and decentralized decisions and actions.	■ ×

Entomological inputs

Establish an entomological component within malaria control programmes	×
Reorient entomological activities to meet the requirements for selective vector control	■

Establish programmes for routine entomological monitoring, active/special surveillance and emergency planning and to support community and intersectoral actions	+
Develop evaluation procedures for entomological activities and vector control	+
Collaborate and interact with research and academic institutes.	+

5. Local capacity/human resource development

Identify knowledge and skills needed for short-term and long-term vector control and entomological activities	+
Define minimum qualifications required for each category of staff	+
Develop training activities and create training opportunities	+
Train staff (in particular entomologists) to have a broader outlook on epidemiology, ecology and social sciences, and develop their managerial skills	+
Develop national expertise	+
Ensure that existing staff have the capabilities required for selective vector control	■
Develop skills for community/intersectoral mobilization	+
Develop skills for information management for selective vector control	+
Develop capacity for comprehensive, integrated control of vector-borne diseases.	■ ×

6. Resources

Mobilize and utilize resources for infrastructure development	×
Mobilize and utilize resources for infrastructure strengthening	■
Coordinate the use of resources from different sources to avoid duplication and waste.	+

7. Operational research

Study and update knowledge of local vectors that are of relevance to interventions	+
Clarify the local relevance of control methods	+

Develop strategies for selective vector control in different epidemiological situations	■ ×
Develop/improve methods for predicting epidemics	+
Examine the complementary effects of using more than one method or strategy in diverse epidemiological situations	■
Develop databases as management tools that incorporate the information needed for selective vector control.	■

Annex 3

Managerial functions at central (national) level in relation to vector control in Category II countries

- Formulating policies and strategies, setting standards, preparing guidelines, coordinating activities related to different approaches to and methods of implementing vector control.
- National-level planning to ensure the development and application of policies and technical and operational criteria for vector control and support services.
- Assessing the local relevance of available vector control methods and strategies.
- Participation in the activities of the national task force for malaria control (see page 51).
- Provision of technical guidance to staff at other levels and to various institutions and agencies.
- Seeking commitment and support for vector control at all levels, including the macroeconomic level (e.g. decision-makers, financial authorities), communities and other sectors.
- Coordinating the exchange of information and experiences, resource utilization and other activities related to vector control in different regions and near country borders.
- Ensuring the existence of a database or information network on vector control-related issues, including new developments at national and international levels.
- Identifying research needs and priorities and supporting, commissioning and coordinating the implementation of research through individual and interactive programmes involving relevant disciplines and sectors and national research institutes.
- Definition of responsibilities for vector control and lines of authority at different levels of implementation.
- Assessing requirements for resources, managing their mobilization and deployment, and monitoring their utilization.
- Monitoring the vector control activities of malaria control programmes and of other agencies to ensure that the specified policies and criteria are adhered to, and that the expected impact is achieved, and providing suggestions for remedial action when required.
- Regular evaluation of the vector control programme.
- Ensuring an adequate local capacity for vector control by: identifying training needs and priorities, mobilizing the necessary resources and planning and participating in training activities.
- Maintaining close collaboration with groups within and outside the health services whose activities may inadvertently increase the potential for mosquito breeding and disease transmission and with those that are involved in or support vector control.

Annex 4

Managerial functions at intermediate level in relation to vector control in Category II countries

- Maintenance of close interaction with the central unit (see Annex 3) in relation to all vector control activities.
- Coordination and monitoring of the implementation of policies and strategies developed at central level.
- Identification of needs and priorities for, and planning of, activities at intermediate and peripheral levels.
- Allocation of resources, including those received from the central level.
- Supervision of operations and assessment of achievements at intermediate and peripheral levels, and provision of feedback to central and peripheral levels.
- Ensuring a timely response to epidemics.
- Undertaking or supporting training activities to ensure that staff at intermediate and peripheral levels are competent and skilled in their assigned jobs.
- Participation and collaboration in problem-solving operational research where relevant.
- Promoting intersectoral and community action in the context of vector control, and giving technical and other support.
- Interacting with neighbouring administrative areas regarding appropriate management of vector control issues of common concern.
- Maintenance of databases of particular relevance to vector control activities at intermediate level.

Annex 5
Vector-borne diseases by country or area as reported to the World Health Organization

Country or area (by WHO region)	Mal[1]	Fil[1]	Den[2]	Je[3]	Yf[2]	Lei[1]	Try[1]	Cha[1]	Sch[1]	Onc[1]
African region										
Algeria						X			X	
Angola	X	X	X		X		X		X	X
Benin	X	X					X		X	X
Botswana	X						X		X	
Burkina Faso	X	X	X		X	X	X		X	X
Burundi	X	X					X		X	X
Cameroon	X	X			X	X	X		X	X
Cape Verde		X								
Central African Republic	X	X					X		X	X
Chad	X	X				X	X		X	X
Comoros	X	X	X							
Congo	X	X					X		X	X
Côte d'Ivoire	X	X	X		X		X		X	X
Equatorial Guinea	X	X			X		X		X	X
Ethiopia	X	X	X		X	X	X		X	X
Gabon	X	X					X		X	X
Gambia	X	X			X	X			X	
Ghana	X	X	X		X		X		X	X
Guinea	X	X	X		X		X		X	X
Guinea-Bissau	X	X			X		X		X	X
Kenya	X	X	X		X	X	X		X	
Liberia	X	X			X		X		X	X
Madagascar	X	X							X	
Malawi	X	X				X	X		X	X
Mali	X	X			X	X	X		X	X
Mauritania	X				X	X			X	
Mauritius		X	X						X	
Mozambique	X	X	X				X		X	X

Country or area (by WHO region)	Mal[1]	Fil[1]	Den[2]	Je[3]	Yf[2]	Lei[1]	Try[1]	Cha[1]	Sch[1]	Onc[1]
Namibia	X					X	X		X	
Niger	X	X				X	X		X	X
Nigeria	X	X	X		X	X	X		X	X
Réunion		X	X							
Rwanda	X						X		X	X
Sao Tome & Principe	X	X							X	
Senegal	X	X	X		X	X	X		X	X
Seychelles		X	X							
Sierra Leone	X	X	X		X		X		X	X
South Africa	X								X	
Swaziland	X								X	
Togo	X	X			X	X	X		X	X
Uganda	X	X				X	X		X	X
United Republic of Tanzania	X	X	X			X	X		X	X
Zaire	X	X	X		X	X	X		X	X
Zambia	X	X				X	X		X	
Zimbabwe	X	X				X	X		X	
Region of the Americas										
Antigua & Barbuda			X						X	
Aruba			X							
Argentina	X					X		X		
Bahamas			X							
Barbados			X							
Belize	X		X			X				
Bolivia	X		X		X	X		X		
Bonaire			X							
Brazil	X	X	X		X	X		X	X	X
British Virgin Islands			X							
Chile								X		
Colombia	X		X		X	X		X		X
Costa Rica	X	X	X			X		X		

Country or area (by WHO region)	Mal[1]	Fil[1]	Den[2]	Je[3]	Yf[2]	Lei[1]	Try[1]	Cha[1]	Sch[1]	Onc[1]
Cuba			X							
Curaçao			X							
Dominica			X							
Dominican Republic	X	X	X			X			X	
Ecuador	X		X		X	X		X		X
El Salvador	X		X			X		X		
French Guiana	X		X		X	X				
Grenada			X							
Guadeloupe			X						X	
Guatemala	X		X			X		X		X
Guyana	X	X	X		X	X				
Haiti	X	X	X							
Honduras	X		X			X		X		
Jamaica			X							
Martinique			X						X	
Mexico	X		X			X		X		X
Montserrat			X							
Nicaragua	X		X			X		X		
Panama	X		X			X		X		
Paraguay	X		X			X		X		
Peru	X		X		X	X		X		
Puerto Rico			X						X	
St Kitts & Nevis			X							
St Lucia			X						X	
St Martin			X							
St Vincent & the Grenadines			X							
Suriname	X	X	X			X			X	
Trinidad & Tobago		X	X							
United States of America			X							
Uruguay								X		
Venezuela	X		X		X	X		X	X	X
Virgin Islands of the United States			X							

Country or area (by WHO region)	Mal[1]	Fil[1]	Den[2]	Je[3]	Yf[2]	Lei[1]	Try[1]	Cha[1]	Sch[1]	Onc[1]
Eastern Mediterranean Region										
Afghanistan	X					X				
Cyprus						X				
Djibouti	X		X			X				
Egypt	X	X				X			X	
Iran (Islamic Republic of)	X					X			X	
Iraq	X					X			X	
Jordan						X				
Kuwait						X				
Lebanon						X			X	
Libyan Arab Jamahiriya						X			X	
Morocco	X					X			X	
Oman	X					X			X	
Pakistan	X					X				
Saudi Arabia	X					X			X	
Somalia	X		X			X	X		X	
Sudan	X					X	X		X	
Syrian Arab Republic	X					X	X		X	
Tunisia						X			X	
United Arab Emirates	X									
Yemen	X					X			X	X
European Region										
Albania						X				
Armenia						X				
Azerbaijan						X				
Georgia						X				
Greece						X				
Israel						X				
Kazakhstan						X				
Kyrgyzstan						X				

Country or area (by WHO region)	Mal[1]	Fil[1]	Den[2]	Je[3]	Yf[2]	Lei[1]	Try[1]	Cha[1]	Sch[1]	Onc[1]
Russian Federation						X				
Turkey	X					X			X	
Yugoslavia						X				
South-East Asia Region										
Bangladesh	X	X	X	X		X				
Bhutan	X			X						
Democratic People's Republic of Korea				X						
India	X	X	X	X		X			X	
Indonesia	X	X	X						X	
Maldives		X	X							
Myanmar	X	X	X							
Nepal	X	X	X	X		X				
Sri Lanka	X	X	X	X						
Thailand	X	X	X	X					X	
Western Pacific Region										
Australia			X							
Brunei Darussalam		X	X							
Cambodia	X	X	X	X					X	
China	X	X	X	X		X			X	
Cook Islands		X	X							
Fiji		X	X							
French Polynesia		X	X							
Guam			X							
Japan				X						
Kiribati			X							
Lao People's Democratic Republic	X	X	X						X	
Malaysia	X	X	X	X						
Marshall Islands			X							
Nauru			X							

Country or area (by WHO region)	Mal[1]	Fil[1]	Den[2]	Je[3]	Yf[2]	Lei[1]	Try[1]	Cha[1]	Sch[1]	Onc[1]
New Caledonia			X							
New Zealand			X							
Niue			X							
Palau			X							
Papua New Guinea	X	X	X							
Philippines	X	X	X						X	
Republic of Korea		X								
Samoa		X	X							
Singapore			X	X						
Solomon Islands	X	X	X							
Tokelau			X							
Tonga		X	X							
Tuvalu			X							
Vanuatu	X	X	X							
Viet Nam	X	X	X	X						
Wallis & Futuna Islands			X							

Cha, Chagas disease; Den, dengue; Fil, filariasis, excluding onchocerciasis; Je, Japanese encephalitis; Lei, leishmaniasis; Mal, malaria; Onc, onchocerciasis; Sch, schistosomiasis; Try, trypanosomiasis, excluding Chagas disease; Yf, yellow fever.

[1] Disease considered to be endemic.

[2] Cases reported to WHO between 1975 and 1993.

[3] Cases reported to WHO between 1988 and 1992.

For countries that are not listed, no cases were reported or no information was available.

Annex 6

Research priorities related to implementation of the Global Malaria Control Strategy

- Stratify geographical and ecological zones for malaria control.
- Identify criteria to determine whether to commence, withdraw or continue indoor residual spraying at local level.
- Establish the most appropriate size of operational areas or units for precise targeting of interventions.
- Establish the residual effect (persistence) of candidate insecticides.
- Identify sociocultural factors and operational and managerial barriers affecting the cost-effective delivery of vector control measures.
- Examine the efficacy, cost-effectiveness, acceptability and use of available control tools in areas with different ecological and epidemiological characteristics.
- Design and evaluate integrated/selective vector control strategies based on sound field research, and develop optimal strategies for cost-effective implementation.
- Determine the role of the different vectors in disease transmission, especially in areas of high risk.
- Classify the breeding habits of different vectors in relation to larval ecology and the flight-range of adults to determine the feasibility of larval control.
- Develop and improve field techniques aimed at better understanding of vector populations and transmission dynamics. Techniques are needed, for example, for:
  - sampling mosquitos for more accurate measurement of human-biting rates;
  - making more accurate estimates of vector age or survival;
  - measuring resistance and establishing diagnostic dosages for detecting resistance to insecticides that have a rapid knockdown effect.
- Develop better indicators of epidemic risks and epidemics and mechanisms for alerting those responsible for action and ensuring a timely response.
- Examine the potential of remote sensing and geographical resource information databases for forecasting epidemics.
- Conduct feasibility studies on strategies for reducing the transmission of infection in areas in which multidrug resistance occurs.
- Establish principles for managing insecticide resistance.
- Develop or improve vector control methods that are locally affordable.
- Search for and test repellents derived from local plants known to possess insecticidal properties.

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