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**Matters for consideration or action by the Conference of the Parties:
measures to reduce or eliminate releases from intentional production and use: DDT**

**Report of a World Health Organization study group on malaria
vector control and personal protection ****

Note by the Secretariat

As referred to in the note by the Secretariat on evaluation of the continued need for DDT for disease vector control and alternative strategies to replace DDT (document UNEP/POPS/COP.2/4), the annex to the present note contains a report of a World Health Organization (WHO) study group on malaria vector control and personal protection (WHO Technical Report Series: 936). The report is made available as submitted by WHO.

* UNEP/POPS/COP.2/1.

** Stockholm Convention, Article 3 and Annex B, part II; report of the Conference of the Parties on the work of its first meeting (UNEP/POPS/COP.1/31), annex I, decision SC-1/25.

MALARIA VECTOR CONTROL AND PERSONAL PROTECTION

Report of a WHO Study Group



**World Health
Organization**

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Report of a WHO Study Group



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Contents

1. Introduction	1
2. The role of vector control in malaria	2
3. Malaria control measures	4
3.1 Measures with broad applicability	5
3.1.1 General applicability of indoor residual spraying	5
3.1.2 General applicability of insecticide-treated mosquito nets	6
3.2 Insecticide resistance in malaria vectors	7
3.3 General indications for different vector control measures	9
4. Eco-epidemiological types and stratification	11
4.1 The Global Malaria Control Strategy and the proposal of eco-epidemiological types	12
5. Effectiveness and challenges of implementing malaria vector control and personal protection strategies in the context of the various eco-epidemiological types	13
5.1 Steady state ecosystems	13
5.1.1 African savannah	13
5.1.2 Plains and valleys outside Africa	16
5.1.3 Forest and forest fringes	19
5.1.4 Highland and desert fringes	24
5.1.5 Wetland and coastal areas	29
5.1.6 Urban and peri-urban areas	32
5.2 Situations of rapid development change	35
5.2.1 Agricultural development projects	35
5.2.2 Socio-political disturbances	39
6. Health systems and malaria	43
6.1 Trends in global initiatives	44
6.2 Trends in local initiatives	44
6.3 Health system dependency	45
6.3.1 Access	45
6.3.2 Targeting	45
6.3.3 Provider compliance	46
6.3.4 Consumer adherence	46
6.4 Implications for malaria vector control and personal protection	46

6.4.1 Decentralization.....	47
6.4.2 Sector-wide approach.....	47
6.4.3 Debt relief and poverty reduction strategy papers.....	48
6.4.4 Integration.....	49
6.4.5 Public-private alliances and contracting out.....	49
6.4.6 Capacity strengthening.....	50
7. Conclusions and recommendations.....	51
7.1 On appropriate strategies and operational issues in eco- epidemiological settings.....	51
7.2 On health systems.....	53
Acknowledgements.....	54
References.....	56
Annex.....	61

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Geneva, 12–14 March 2004

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1. Introduction

A World Health Organization (WHO) Study Group on Malaria Vector Control and Personal Protection met in Geneva, 10–12 March 2004. The meeting was opened on behalf of the Director-General by Dr Jack Chow, Assistant Director-General, HIV/AIDS, TB and Malaria. Dr Chow expressed the WHO concern that, despite national and global efforts to control malaria, the disease burden remains high, especially in tropical Africa. The situation is further compounded in emergency situations. He stated that it was therefore necessary to review the current vector control strategies and their effectiveness in various operational and eco-epidemiological settings and to identify the challenges for implementation in different health systems. These would serve as a basis for the development of a strategic framework for strengthening malaria vector control implementation.

The Roll Back Malaria (RBM) Initiative was launched by the WHO Director-General in 1998 as a Cabinet Project to coordinate global actions against malaria. The Initiative was then endorsed by the Executive Board (Resolution EB 103.R3) and thereafter by the World Health Assembly (Resolution WHA 52.11). RBM recognized that in order to revitalize the attack on malaria it was necessary to have the skills and financial support from an exceptionally broad range of partners. It called for the commitment of interested partners at global, regional and country levels, to join in sustained technical and operational support to endemic countries to reduce as much as possible their malaria burden, while stimulating and supporting research and product development to cope with emerging problems. Technically, RBM endorsed the Global Malaria Control Strategy (GMCS) (1), adopted by the Ministerial Conference in Amsterdam in 1992, and its four main objectives:

1. to provide early diagnosis and prompt treatment of malaria;
2. to plan and implement selective and sustainable preventive measures, including vector control;
3. to detect early, contain or prevent epidemics;
4. to strengthen local capabilities 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.

The RBM goal is to reduce the global malaria burden by half by 2010 as compared to 2000.

In April 2000, RBM organized the first Summit on malaria in Abuja, Nigeria. The Summit which brought together African Heads of State and Government set three main targets (2) to be reached by 2005, and estimated that it was necessary to obtain US\$ 1 billion each year to reach the stated targets. These targets in both funding and achievement remain good terms of reference for the global initiative which is gaining momentum, even if at a slower pace than expected. In 2001, the UN General Assembly declared 2001–2010 the decade to roll back malaria in developing countries, particularly in Africa (3).

Today, the RBM Initiative has united over 90 partners – malaria endemic countries, multilateral and bilateral donors, nongovernmental organizations (NGOs), civil society, academia, and private organizations – in a strong political commitment to collaborate and coordinate their efforts to achieve technical consensus, increase efficiency and reduce duplication of efforts.

2. The role of vector control in malaria

Vector control remains the most generally effective measure to prevent malaria transmission and is therefore one of the four basic technical elements of the GMCS.

Before the discovery of dichloro-diphenyl-trichloroethane (DDT), the main approach to controlling anopheline vectors was directed towards the larval stage, which required a detailed knowledge of the bionomics of local vectors. In some cases, a high level of community participation (often enforced by legislation) and a continuity of effort for decades was needed to ensure slow but often sustainable progress. Only in projects of very high economical and political value was a highly disciplined organization rigorously enforcing the application of antilarval measures able to achieve spectacular successes, even in relatively large areas, notably the eradication of invading populations of *Anopheles gambiae* from Brazil and Egypt or the sanitation of the Pontine Marshes in the Roman Campagna. In other cases, detailed knowledge of species habitats led to methods of environmental manipulation and sustained, cost-effective control, as in parts of Malaysia and Indonesia. In each situation, the solution of a local malaria problem required an in-depth study by a multi-disciplinary team to design a multi-sectoral programme, often including environmental sanitation, modification or manipulation, the use of larvivorous fish as predators, petroleum oils and Paris green.

The residual effect of DDT against the adult stage of malaria vectors, which required no more than one or two treatments per year, made it operationally feasible to extend malaria vector control to extensive rural areas. Moreover, soon after DDT became available and proved successful for indoor residual spraying (IRS) it was shown that, other things being equal, the indoor application of residual adulticides has the great advantage of repeated chances of killing female anophelines whenever they visit sprayed houses in search of human bloodmeals. Thus, if a feasible percentage of houses in a village (e.g. 80%) are effectively treated with a residual adulticide the likelihood of a female mosquito escaping death on each of its house visits and picking up gametocytes from malaria-infected persons and becoming infective (with sporozoites in salivary glands) is extremely small.

These theoretical considerations and the early practical experiences in the use of DDT for malaria control suggested that complete coverage with IRS during a period sufficiently long for every malaria infection to die out, would lead to the eradication of the disease. The early experiences in southern Europe, North America and Taiwan seemed to confirm those expectations. IRS with DDT, and later with other residual insecticides, became the backbone of the malaria eradication campaign launched in 1955. However, the success of IRS depends largely on the mosquitoes resting indoors before or after feeding – not all species do this naturally and the excito-repellency of DDT and pyrethroids may dissuade mosquitoes from resting long on sprayed surfaces. Other requirements include the need that human shelters have walls to be sprayed, access to the interior of all houses, and a relatively stable human population without a high frequency of replastering of sprayable surfaces. The conditions for “eradication” were not met in all malaria areas, especially in Africa, where serious efforts were never mounted. In addition, the logistic, human and financial resources needed to sustain this effort were only met in a limited number of countries, which led to abandonment of the concept of eradication. The return to a strategy of malaria control requires attention to both disease management and transmission reduction via vector control. The fundamental action is vector control, which, if effective, will reduce the number of cases requiring treatment. The integration of preventive services – such as vector control – into health services primarily oriented towards treatment is a formidable challenge that calls into question the nature and level of planning and implementation of essential vector control functions. The effective deployment of such functions is a pre-condition for successful and sustained control of malaria.

3. Malaria control measures

The deterioration of IRS programmes in some countries led to the resurgence of malaria and the abandonment of the global campaign for eradication. Eventually, this failure spurred renewed interest in anti-larval and personal protection measures for reduction of malaria transmission. The current malaria control strategy calls for the selection of those control measures which are most appropriate to local circumstances and capabilities and malaria risk. Vector control measures vary considerably in the scope of their applicability. Table 1, adapted from Bruce-Chwatt (1985), lists the currently available control measures according to their effect and indication for community or personal protection.

Table 1. Malaria vector control measures

Action	For individual and family protection	For community protection
Reduction of human-mosquito contact	Insecticide-treated nets, repellents, protective clothing, screening of houses	Insecticide-treated nets zoophylaxis
Destruction of adult mosquitoes		Insecticide-treated nets, indoor residual spraying, space spraying, ultra low-volume sprays
Destruction of mosquito larvae	Peri-domestic sanitation	Larviciding of water surfaces, intermittent irrigation, sluicing, biological control
Source reduction	Small-scale drainage	Environmental sanitation, water management, drainage
Social participation	Motivation for personal and family protection	Health education, community participation

3.1 Measures with broad applicability

Control measures directed towards adult mosquitoes – IRS and insecticide-treated nets (ITNs) – are more broadly applicable geographically than more location/ecology specific measures directed towards larvae. Many important vectors of malaria bite indoors at night, and may rest on indoor surfaces after biting, whereas larval habitats vary markedly among anopheline species.

The development of pyrethroids with long residual action and very low mammalian toxicity suggested the possibility of treating mosquito nets to add an insecticidal effect to their mechanical protection, as mosquitoes are positively attracted by the odour of the sleeper inside the net, making the ITN like a baited trap. The insecticidal treatment of nets adds a chemical barrier to the often imperfect physical barrier provided by the net and thus, improves its effectiveness in personal protection.

In addition to personal protection for sleepers under mosquito nets being greatly enhanced by insecticide treatment, there is much evidence that community-wide use of ITNs leads to large-scale killing of mosquitoes (4, 5) in areas where vectors are highly anthropophilic. The community-wide use of ITNs reduces the vector population and shortens the mean mosquito lifespan (6). As a result, this will reduce the malaria sporozoite rate because, as with IRS, very few mosquitoes will survive long enough for the sporogonic cycle to be completed. Apart from their killing effect, ITNs will also inhibit mosquito feeding, hence reducing the reproductive potential of highly anthropophilic vectors. These characteristics mean that ITNs may be considered also a vector control measure of general applicability. As with IRS, the vector control effects of ITNs become more apparent when household coverage increases.

3.1.1 General applicability of indoor residual spraying

IRS remains the most widely used malaria vector control method. Its application has been thoroughly standardized and there are clear specifications for suitable equipment and insecticides. Field guidelines on technical and operational issues are available in almost all languages of malaria-endemic countries.

As the main effect of IRS is the killing of mosquitoes entering houses and resting on sprayed surfaces; it is not useful for the control of vectors which tend to rest outdoors, although it may be effective against outdoor biting mosquitoes which enter houses for resting after feeding.

IRS is a method for community protection and, to achieve its full effect, IRS requires a high level of coverage, in space and time, of all the surfaces where the vector is likely to rest, with an effective dose of insecticide. The selection of the insecticide has to take into account the susceptibility status of local vectors and duration of the residual effect in relation with the length of the transmission season.

IRS requires the acceptance of the population of spraying once or twice a year and a reasonable preservation of sprayed surfaces without replastering, in contrast with ITNs, which requires the continuous use of the treated nets. Thus IRS is more suitable than ITNs for the rapid protection of a population, although when IRS needs to be continued for many years, there may be an attrition of people's acceptance of spraying. In contrast, ITNs are more suitable for progressive introduction and incorporation into sustainable population habits.

3.1.2 General applicability of insecticide-treated mosquito nets

a. Effects of targeted groups versus community-wide provision of insecticide-treated nets

Comparison of malaria morbidity (fever and anaemia) and all-cause mortality in children without their own nets in houses or villages adjacent to those with widespread ITN use show improved survival and health. This community-wide effect has been observed in Ghana, coastal Kenya, western Kenya, Papua New Guinea and the United Republic of Tanzania. The strength of the community-wide effect of ITNs appears to be at least as great as the personal protection effect, and the entomological data support the idea that relying on personal protection alone would lose a significant proportion of the potential benefit that community-wide provision of ITNs could achieve. Such studies suggest that community-wide distribution of ITNs would be cost-effective.

b. "Rebound" from partial control of malaria transmission

In areas of intense perennial transmission, the development and maintenance of high levels of immunity is a critical determinant keeping the malaria burden under control. It has been argued that the effect of partial transmission control might interfere with this natural process and thus postpone malaria morbidity and deaths until later in childhood and early adulthood. Hence it may not achieve an overall reduction in the burden. Even worse would be the postponement of malaria attacks to an age at which severe effects such as cerebral malaria are more common. Much of the discussion of this topic has been based on areas of natural low

transmission as surrogates for what would occur in previously highly endemic areas after prolonged application of vector control, e.g. by use of ITNs. Data from Burkina Faso (7), western Kenya (8) and the United Republic of Tanzania (9) do not support these ideas. In all locations, mortality reduction in children was sustained over 4–6 year periods.

c. *Treated versus untreated nets*

Untreated nets alone, when properly used and well maintained, have been estimated to be responsible for about half of the protective effect of ITNs. It is often considered that one of the main drawbacks of ITNs is the low re-treatment rate, which was quite often observed even with large Information, Education and Communication (IEC) campaigns. However, the promotion of nets must be maintained and increased even if the low rate of re-treatment remains a problem to be solved. Re-treatment of nets must be free of charge for everyone and regularly done on a large-scale basis.

With the newly developed long lasting insecticidal nets (LLINs), the issue of net re-treatment may be resolved as long as the price is not prohibitively increased by the specific treatment.

3.2 Insecticide resistance in malaria vectors

The use of insecticides for vector control requires that target species are effectively susceptible to the insecticides under the conditions in which they are used in the field. Insecticide resistance has been commonly recorded by laboratory tests in many malaria vector populations throughout the world (10). Resistance can be due either to detoxification of insecticide by enzymes or by mutation on its target site: sodium channels for DDT and pyrethroids (*kdr*), and acetyl-cholinesterase for organophosphates and carbamates.

Since *kdr* mutation was first detected in *An. gambiae* from Africa in 1998 (11, 12), molecular monitoring has been intensified. This mutation was found almost exclusively in the S molecular form of the *An. gambiae* “group” (13) in West and Central Africa. More recently, this mutation was found in southern Benin, Côte d’Ivoire and Burkina Faso in the M molecular form (14). Impact of the *kdr* mutation on the efficacy of pyrethroid treated nets has been investigated in Benin and Côte d’Ivoire. However, among free flying wild mosquitoes entering experimental huts in these areas, mortality remains high and the personal protection from biting remains good (15–17). A different “*kdr-type*” mutation (leucine-phenylalanine) has been found in *An. gambiae* in western Kenya where a large ITN project run by the US

CDC was highly successful. The same mutation has also been found in other malaria vectors such as *An. stephensi* and *An. sacharovi* (18).

Metabolic resistance to pyrethroids in malaria vectors has been recently found in several major vector species including *An. funestus* in South Africa for which a switch back from pyrethroid to DDT spraying was required to restore malaria control. Outside Africa, metabolic pyrethroid resistance has been found in *An. sudaicus* from southern Viet Nam, a vector of local importance in this area.

Although resistance to organophosphates has been found in several major malaria vector species, there is little documented information on its impact on spraying programmes. Recently, a mutation conferring resistance to carbamates and organophosphates has been detected in West Africa in the major malaria vector *An. gambiae* (19). However, in experimental huts in the area concerned, ITNs treated with the carbamate carbofuran or the organophosphate chlorpyrifos methyl caused mosquito mortality at least as high as with pyrethroid-treated nets (20). The gene responsible for the target site mutation has been identified and a molecular assay is now available.

It is considered that the most practical approach to resistance management in residual spraying programmes is the rotation of unrelated insecticides according to a pre-arranged plan or the switching of insecticides in response to the results of resistance tests. The latter strategy has been successfully implemented in the Onchocerciasis Control Programme and in Mexico where a pre-arranged plan of annual switching between three different insecticides led to slower build-up of pyrethroid resistance than continual use of a pyrethroid.

The use of mixtures of unrelated insecticides or treatment of different parts of a net with different insecticides is thought to be promising (21, 22). The combination of two safe and effective insecticides on the same net offers great potential.

Resistance management relies on proper resistance monitoring. This activity has to be integrated as a component of any malaria vector control programme. In the context of long-term implementation of ITN and spraying programmes, as a precaution against the emergence of strong forms of pyrethroid resistance, it is vital to stimulate the search for alternative insecticides, with molecules acting on new target sites, to allow effective and sustainable implementation of malaria and other vector-borne disease control programmes (23). Equally vital in the long run is the progressive reduction in reliance on single insecticides and single interventions.

3.3 General indications for different vector control measures

As already pointed out, long before the extensive use of ITNs, remarkable progress against malaria was achieved by IRS. It is important to arrive at rational criteria for choosing between these methods. At present it seems that the choice is made on whether or not the country has a national IRS tradition and the structures to deliver the intervention in time and with the required coverage rate.

In areas where malaria vectors are fully susceptible to pyrethroids, side-by-side comparison of the same pyrethroid used for both methods against malaria transmitted by *An. gambiae* s.s. and *An. funestus* showed very similar impact on the entomological inoculation rate (EIR) of the vector population, incidence of malaria infection and malaria morbidity in children. A review of the remarkable results achieved in the 1950s, 1960s and 1970s with IRS in highly endemic areas of Africa shows that so far none of the recent ITN trials has done as well. However, IRS programmes were larger in scale than the relatively smaller ITN efficacy trials, so the comparison conflates two methods and scales of intervention.

Cost comparisons of IRS and ITNs yielded surprisingly variable results. The encouraging past results with IRS in tropical Africa did not lead to nationwide campaigns. It can be argued that this has been because in very low income countries it is not possible routinely to meet the logistical demands of ensuring that trained spray teams equipped with working spray pumps and sufficient insecticide arrive at each village in time to spray before the malaria season. It can also be argued that it is more feasible to supply ITNs in such circumstances because this does not impose similar logistics requirements.

Moreover, the experience of long-term use of IRS by organized antimalaria campaigns in many parts of the world has frequently shown a progressive development of people's fatigue and reluctance to allow intrusion into their homes. This phenomenon may be less likely to occur with the use of ITNs, which are far more under the control of households. In contrast, in rapid response to epidemics there are good reasons to favour a trained and equipped IRS "fire brigade" capable of moving quickly to an area where there is a high likelihood of a malaria epidemic unless quick action is taken.

Although in principle IRS and ITNs can be considered to be more or less suitable everywhere, there is an essential difference between the two. The personal protection provided by ITNs allows their deployment in a progressive way, starting with low population coverage, as is currently the case in most rural areas of tropical Africa. Nonetheless, rapid scale-up is highly

desirable. IRS, on the contrary, requires, from the beginning, high coverage and quality of spraying in order to be effective. A comparison of the basic requirements for the implementation of IRS, ITNs and larval control is summarized in Table 2.

There is a significant difference between the almost general applicability of IRS and ITNs and the highly specific indications of all forms of larval control, which require a much more detailed knowledge of vector breeding places and bionomics.

Table 2. Requirements for successful use of indoor residual spraying, insecticide-treated nets and larval control for malaria vector control

Indoor residual spraying	<ul style="list-style-type: none"> • Indoor resting vectors (endophilic species) • Houses with walls and ceilings • Most malaria infections acquired indoors (endophagic species) • People not nomadic (permanent homesteads) • Willingness to accept spraying • Ability to organize the delivery of spraying on time to all malaria areas including information on number and location of houses to be sprayed
Insecticide-treated nets	<ul style="list-style-type: none"> • At least some of the vector biting at hours when and where people are in bed • Willingness of people to use nets • An adequate delivery system for nets and insecticide including information on number and location of houses and sleeping units requiring nets • Ability to organize a net treatment programme free of charge or to switch to use long-lasting insecticidal nets
Larval control	<ul style="list-style-type: none"> • Breeding in semi-permanent sites • Ability to locate and map out a very large proportion of the breeding sites within mosquito flight range of the community which it is required to protect • Proper selection of anti-larval measures (e.g. use of larvivorous fish, bacteria, oiling) • Community participation for mosquito breeding sites reduction and/or elimination

4. Eco-epidemiological types and stratification

Although anti-larval and physical personal protection measures have rather limited applicability, they may be effective under certain conditions and be more easily sustainable than IRS or an ITN programme. The problem is to recognize which approaches might work best under which circumstances. The process is guided by the recognition of eco-epidemiological and socio-economic factors indicative of particular vector bionomics, human/vector contact patterns and the operational feasibility of certain control measures. Stratification is the process of identifying the areas where different approaches to control would be indicated.

Stratification is defined as “the process of uniting areas, populations or situations that exhibit a relative resemblance of a set of specified relevant characteristics, thereby distinguishing them from other areas, populations or situations dissimilar by the same set of characteristics” (24). The term stratification suggests the superposition of the known geographical distribution of variables. Stratification may therefore be undertaken by selecting a number of variables that may be considered as main determinants of the intensity of malaria transmission, such as distribution of main vector species, altitude, temperature, humidity, rainfall and distribution of rural/urban population. Each of these variables is then mapped with iso-lines separating ranges of relevant intensity. Maps of these variables can then be overlaid with maps showing the recorded malaria prevalence of past (or recent) surveys and the data on malaria incidence from existing health facilities. Stratification should therefore be considered not only as an exercise in programme planning that uses existing knowledge, but also as a process of analysis of accumulated knowledge as programme experience develops and adjustments are required.

Following the recommendations of the 17th session of the WHO Expert Committee (25), most country programmes made some attempts to stratify their malaria problems, but the interpretation of what was meant by stratification varied widely from programme to programme. Sometimes, those countries which tried to follow the recommended overlay of the distributions of relevant variables ran into serious difficulties, including the lack of capacity to process the amount of data that was accumulated, often derived from questionnaires.

4.1 The Global Malaria Control Strategy and the proposal of eco-epidemiological types

The GMCS, published in 1992, suggested that “the traditional approach to identification of major malaria zones by stratification has recently given way to a more pragmatic approach. This involves the identification of a limited number of main ecological prototypes based on accumulated empirical experience, their further characterization by local determinants, and the establishment of a link between situations with certain characteristics and specific options for control. On the basis of readily available information, seven dominant epidemiological types of malaria were identified. For each of these, certain risks are particularly important and certain approaches to control more likely to succeed than others”.

Nonetheless, stratification or identification of eco-epidemiological types often seem to have remained at the level of theoretical discussions, while actual control programmes continue to seek operational solutions of general applicability and do not develop the human resources needed to identify their various specific problems allowing the application of more differentiated control methods.

The stated seven prototypes do not necessarily represent all possible variants of malaria epidemiology worldwide. On the contrary, in some situations, the most relevant stratification may require distinguishing between the sub-divisions of the seven prototypes. Moreover, those prototypes are not mutually exclusive and mixed situations are frequently found (e.g. forest and altitude fringe, dry savannah and river forest corridors). Such is the case for the Neotropics where different eco-epidemiological regions have been identified and characterized (26). The prototypes identified may be considered as nodes in a continuous field of variation, showing gradients in most variables.

5. Effectiveness and challenges of implementing malaria vector control and personal protection strategies in the context of the various eco-epidemiological types

The GMCS identifies eco-epidemiological types that fall under two main categories and that will be used to discuss the different indications for specific vector control measures. The first three types (“tropical African savannah”, “plains and valleys outside Africa” and “forests and forest fringes”) represent a form of background against which the other types occur, either on the margins or as islands of greater or lesser extent.

5.1 Steady state ecosystems

5.1.1 Tropical African savannah

From the Sahara desert to the humid equatorial Afrotropics (inter-tropical convergence zone), malaria eco-epidemiology can be discussed in relation to three main agroclimatic types:

- a. the Sahel “pastoral zone” has rainfall less than 200 mm/year and xerophilous steppe, grading southwards to dry savannah vegetation with annual rainfall of about 400 mm and precarious cultivation;
- b. western and central African belts of progressively more humid “sudano-sahelian”, “sudanese” and “sudano-guinean”, and “guinean” savannah vegetation grading into equatorial rainforest, with one main rainy season per year with a total rainfall of 500–1200 mm. These ecozones cover 3 million km² with 25–30 million inhabitants and rapid population growth in 16 countries: Benin, Burkina Faso, Cameroon, the Central African Republic, Chad, Côte d’Ivoire, Gambia, Ghana, Guinea-Bissau, Guinea Conakry, Mali, Niger, Nigeria, Senegal, Sudan and Togo;
- c. extensive savannahs (dominated by *Acacia*, *Balanites* and *Brachystegia* trees) covering much of eastern and southern Africa, between the equatorial rain-forest and temperate highlands and subtropical south.

5.1.1.1 Malaria vectors and transmission

The main reason why malaria in tropical Africa is much worse malaria than in other parts of the world is because two of the world’s most efficient

vectors of malaria alternate in abundance seasonally throughout the savannahs: *An. funestus* breeding prolifically in grassy swamps to produce peak population densities towards the end of the rainy season and into the dry season; members of the *An. gambiae* complex breeding opportunistically in freshwater temporary pools wherever they occur with rainfall, irrigation, borrow pits or other man-made sites prone to flooding, such as footprints and road ruts. The two most important members of the *An. gambiae* complex are *An. arabiensis*, with females blood-feeding on livestock or humans plentifully indoors or outdoors, and *An. gambiae* s.s. with females more likely to bite humans indoors. Evidently these anophelines have coadapted to human ecosystems in the Afrotropical savannah where their combined contributions to malaria transmission have apparently facilitated the evolution of falciparum malaria (27, 28). Due to their endophilic and anthropophilic behaviour, *An. funestus* and *An. gambiae* s.s. seldom occur away from human habitations. Their exceptionally high vectorial capacity can be attributed to their endophilic resting behaviour, allowing relatively longer survival rates than for exophilic adult mosquitoes, as well as their propensity to feed on humans repeatedly.

In the western savannah, the main vectors are *An. gambiae*, M and S molecular forms, *An. arabiensis*, which can live in drier area than *An. gambiae* (although this species has been found in the northern part of Mali) and *An. funestus*, which almost disappeared during the drought period and seems to recolonize its area of distribution. Several other species are found in savannah areas including *An. nili* that may be a locally important vector, as well as *An. coustani* and *An. pharoensis*.

Malaria transmission is typically intense, regular, long, perennial or seasonal, according to the rainfall pattern and presence of water bodies around human communities. Transmission is very much influenced by the local ecological situation of each village, nearby river, swamp, backwater and human ways of life – both on a small scale (near pits from which soil is taken for brick making, footprints in marshy ground, etc.) as well as a large scale (small or large dams, rice fields, etc.). In these conditions, the annual entomological inoculation rate is very high, often between 50 and 350 infective bites/human, and prevalence of *Plasmodium* is variable during the year, from around 50% during the dry season to more than 80% at the end of the rainy season in children under five years.

“Malaria” is the leading cause of presentations at clinics and hospitalization. Actual malaria morbidity represents around 30–40% of all fevers registered in health centres, with a great variation during the year, from less than 10% at the end of the dry season to more than 80% at the end of the rainy season.

5.1.1.2 Vector control issues and challenges

Africa south of the Sahara, except for South Africa and some of the islands, was not incorporated into the global malaria eradication campaign of 1955–1969, except for a number of pilot projects aimed at examining the feasibility of interrupting malaria transmission. Therefore, few of the countries developed the infrastructure to undertake IRS on a national scale. As a consequence, most countries have concentrated their malaria control efforts on the development of primary health care to make appropriate disease management accessible to the whole population, limiting mosquito control to urban areas and certain economic development projects.

This situation weighted heavily in favour of ITNs versus IRS as the malaria vector control measure of choice for tropical Africa. Moreover, the personal protection afforded by ITNs made it possible to plan its implementation as a promotional programme aiming at a progressive increase in coverage before reaching the level of coverage necessary for community protection.

The major challenge is that, in spite of the Abuja Declaration, coverage progresses at a slow pace. According to the “Africa Malaria Report, 2003” (29), “the proportion of children under five years sleeping under nets is low – about 15% children across 28 countries surveyed. Even fewer children (less than 2%) sleep under ITNs”. Only few countries reported use rates of more than 10%” although the availability of nets has increased appreciably over the last 10 years.

The challenge is clear: how to scale up from the current 5% (and less) to the targeted 60% and more, if possible. Two main situations are well known to occur in Africa south of Sahara:

- a. absence of nets in the household for many reasons, such as net availability and affordability, environmental conditions (e.g. ambient temperature), competing needs, cultural barrier, etc.;
- b. when nets are present in houses and used, they are often not treated or re-treated.

These points constitute the three main obvious challenges:

- a. to increase the possession of nets for every member of every family,
- b. to increase the use of nets for every member of every family,
- c. to promote net treatment, either by an organized service, by the users themselves (for those who already have nets) or by introducing LLINs.

The use of mosquito nets is usually linked to protection against nuisance mosquitoes, bedbugs, flies, cockroaches, “things falling from the roof”, etc. and less frequently indeed, to malaria prevention.

5.1.2 Plains and valleys outside Africa

It is in such areas with a relatively stable agricultural economy that the main successes of the global eradication campaign, based on IRS, were achieved. As a result, malaria has been almost or completely eradicated from almost all Caribbean islands, Europe, North Africa, North America, and the southern cone of South America, and considerably reduced in southern Africa and extensive areas of Asia. Malaria control was not as successful, in spite of conscientious application of IRS, in areas with:

- a. transformation of agricultural infrastructure (irrigation, concentration of land ownership, road construction) that created poles of economic development, thus setting up areas of a new eco-epidemiological type;
- b. rural-urban migration with rapid development of peri-urban areas;
- c. modification of agricultural practices, introduction of cash crops and progressive extension of their cultivation, increasing use of migrant temporary labour.

5.1.2.1 Malaria vectors and transmission

The principal vectors of malaria in South Asia are: *An. culicifacies* (in plains); *An. fluviatilis* and *An. minimus* (in river valleys); *An. stephensi* (in arid, semi-arid plains and cities) while *An. annularis*, *An. philippinensis* and *An. aconitus* (in eastern coastal areas) are considered secondary vectors. *An. sinensis* and *An. anthropophagous* are vectors of malaria in China. *An. darlingi* and *An. pseudopunctipennis* are main malaria vectors in Central and South America.

Vectors in foothills and medium altitude valleys are more efficient than in the plains in South and South-East Asia (e.g. *An. fluviatilis* and *An. minimus*), while the opposite is the case in Central and South America (*An. pseudopunctipennis* and *An. nuneztovari*).

While in most areas of Africa, America and Europe, malaria transmission was most intense in the plains and people found refuge from it by building their villages in the hills, in South-East Asia, anophelines of the plains seem to have considerably less vectorial ability, even if subsequent to extensive irrigation very high densities of *An. subpictus*, *An. annularis* or even *An. minimus* are produced. Malaria transmission is very intense, in contrast, on the foothills and medium altitude valleys, where anophelines such as *An. fluviatilis* or *An. minimus* are the most efficient vectors of malaria.

Malaria in plains and river valleys is often seasonal or, in humid tropical areas, perennial with marked seasonal peaks associated with agricultural cycles,

and determined by availability of surface water, temperature, humidity, climatic variations and other physical perturbations (30). It mainly occurs in either hypoendemic or mesoendemic form. Transmission occurs from late spring to autumn (monsoon in South-East Asia) with *P. vivax* being the predominant parasite, it generally produces a high relapse rate in spring, i.e. just before the onset of rains, followed by a wave of transmission during the whole summer. *P. falciparum* transmission often occurs mainly in late summer and autumn, adversely affecting crop seasons. In regions where *vivax* predominates, malaria transmission rates are generally low, people of all ages may be affected and human populations develop little immunity to the parasite. *P. falciparum* prevalence usually remains low, eventually causing epidemics with high mortality when rains are abnormally intense and prolonged. In addition, failure of monsoons causes drought and, in areas of well-kept agriculture, strings of pools in the drying river beds becoming highly productive breeding places for malaria vectors cause epidemics in riverside villages.

Development activities alter vector ecology and may increase malaria transmission risks. Irrigation schemes, agricultural development and colonization, combined with attraction of temporary labour and the establishment of labour camps, have been frequent causes of resurgence of malaria. In general, the flow of human migration from poorly developed areas towards developed ones also contributes to increased malaria transmission and may cause malaria epidemics. Agricultural development projects are discussed below as a separate eco-epidemiological type.

Natural disasters such as hurricanes may have a severe impact on health and particularly on malaria, because of an increase in malaria transmission, not only due to increased exposure of the population, but often also to their negative effect on the health services, e.g. hurricane Flora drastically disrupted the malaria eradication campaign of Haiti in 1963; a massive earthquake in western India in 2001 destroyed infrastructure and housing, and led to a severe malaria outbreak.

5.1.2.2 *Vector control issues and challenges*

IRS remains the main method of vector control. Challenges for the appropriate use of IRS include refusal of spraying; replastering of sprayed surfaces; vector resistance, avoidance and exophily; poor planning; poor quality house coverage; rising cost of insecticides to replace DDT where there is DDT resistance; agricultural use of insecticides leading to a faster development of resistance to insecticides; mass destruction of houses in earthquakes etc., all of which may impede IRS.

The use of ITNs is being scaled up and large-scale community-supported ITN programmes are operational in Cambodia, China, Indonesia, Lao People's Democratic Republic, Philippines and Viet Nam. Community-based net treatment programme has been found successful in several countries. Other countries such as Bangladesh, Nepal, and Sri Lanka are promoting the use of ITNs/LLINs. In plains and valleys with meso- to hypo-endemic malaria, use of ITNs/LLINs may be targeted for high risk groups/communities. In Central and South America, ITNs/LLINs would be a rational choice in large areas where endophagic populations of late night-biting mosquitoes such as *An. darlingi*, *An. nuneztovari* and *An. marajoara* are involved in malaria transmission. The challenge is how to scale up access to, and coverage of, affordable treated nets in targeted communities, keeping the elements of equity and sustainability so as to maximize the public health impact.

Large-scale use of larval control, even before the discovery of residual insecticides, has been usually limited to areas of economic importance and will be discussed under the "agricultural development projects" and "urban areas" eco-epidemiological types, as these appear as islands within the rural agricultural areas.

Environmental management and sanitation, which was highly successful in the classical examples of the Roman Campagna, the Sardinia project and the Tennessee Valley, has recently had very little use as a large-scale malaria control method, due to operational difficulties, poor awareness and technical know-how, and lack of initiatives and coordination with relevant sectors.

Similarly, larvivorous fish, particularly *Gambusia affinis* and *Poecilia reticulata*, which constituted the backbone of some malaria control programmes before DDT, has had very limited use, being used almost only in field trials, such as those in northern Afghanistan, Djibouti and Somalia, some villages in Karnataka, India, which show that fish can be used for vector control in specific situations in cities and villages in the plains areas, especially when vectors breed in man-made water collections.

Challenges for targeting the use of larval control include:

- a. shortage of trained personnel with skills for intersectoral cooperation, non-availability of training manuals for mass production and use of larvivorous or weed-eating fish, and achieving use on an operational scale of fish in plains areas as part of an integrated control strategy where such use has good prospects;
- b. lack of interaction and coordination with relevant sectors. The challenge will lie in soliciting community and intersectoral support for these activities, implementation of many of which might require transferring costs back to those sectors that are responsible for creating them.

Malaria epidemics are likely to occur in arid areas, in the altitude fringes or follow massive arrival of displaced populations or refugees from areas of lower endemicity. Early warning or early detection systems are seldom functional, even in known epidemic-prone areas, since epidemiological surveillance is generally weak and not geared towards the rapid detection and reporting of abnormal situations. As a result, most often the epidemics are first reported in the media before health services take note of them. Some programmes have made provisions for maintenance of stores of insecticides, spray equipment, blood slides, and antimalarials. Epidemics often create chaotic situations due to lack of coordination and proper information, and often political considerations require introduction of all known and available interventions irrespective of their scientific merit.

In plains and valleys, the general health services are often inadequate and are related to general economic development. A large proportion of patients with conditions of public health significance have no access to health services. As a result, malaria control in traditional farming areas in plains and valleys goes beyond the boundary of health and requires a multidisciplinary approach.

Intersectoral coordination is weak at the intermediate level where it is needed most. Frequently there is no coordination between agriculture and health and private pest control operators, an exception being Sri Lanka where malathion has been reserved for use in public health in an attempt to delay insecticide resistance to *An. culicifacies*.

5.1.3 Forest and forest fringes

Forest areas are enormously varied, not only in different parts of the world, but also within a single forest, both with regards to basic ecological characteristics and to the malaria risk in them. There are nevertheless a number of common human ecology features of epidemiological and operational importance. Dense primary forest areas have low population density, communications and transport facilities are generally scarce and, except for a few roads, often limited to river navigation, non-motorable tracks, and air transport; human settlements are often quite specialized and isolated from neighbouring ones with different livelihoods.

Malaria risk is often associated with forest areas. For example in the WHO South-East Asia Region, while forest cover represents 18% of the territory of the eight malaria endemic countries, these areas suffer between 31% to 87% of the malaria cases and between 52% and 99% of the *P. falciparum* cases. In South America, over 70% of cases are reported from the Amazon basin and between 50% to 80% of cases are due to *P. falciparum*.

5.1.3.1 Malaria vectors and transmission

Forests and settlements in deforested areas harbour very efficient malaria vectors, particularly *An. gambiae* s.s. (“forest” karyotype) and *An. moucheti* in tropical Africa; *An. darlingi*, *An. marajoara* and *An. nuneztovari* in South America, and *An. dirus* and *An. fluviatilis* in South-East Asia. These vectors preferentially attracted to bite humans in their quite open shelters, but return to rest in the forest vegetation, thus avoiding the effect of any residual insecticides that may have been sprayed on whatever walls or roofs those shelters have. Malaria transmission is therefore more intense and more difficult to control in temporary or newly established forest settlements than in neighbouring savanna farmlands.

As a result of the great variety of human settlements and activities, there is a wide range of epidemiological situations. Nevertheless, for malaria control in large forest areas, a search should be made for the following, which may be considered as representative subtypes:

- a. *Native forest populations of hunters and food gatherers.* These populations often live in quite small and mobile communities, relatively isolated and do not offer the population density and continuity of human-vector contact needed to maintain the endemicity of *P. falciparum*. Nevertheless, when, as is happening now in some areas of the Amazon, these populations come in close contact with gold miners and settlers, *P. falciparum* malaria ravages whole communities, since forest anophelines are generally very efficient vectors of *P. falciparum*. Malaria is therefore contributing to the disappearance or the severe decline of some forest tribes.
- b. *Agricultural activities of forest areas.* These activities imply either large scale deforestation or swiddening. The former is now the most common form, leading to a continuous trend, with an average loss of tropical forest estimated at 11 million hectares per year (FAO, 1989). In contrast, the latter, in its most traditional and organized manner, practised for centuries by the inhabitants of villages in the immediate vicinity or in clearings in the forest consists of slash-and-burn agriculture. As a result of increased economic demands and commercial exploitation of timber, which is reducing the area available, swidden cycles are becoming shorter, therefore preventing the proper regeneration of the forest and causing land degradation; the greater distances involved make more difficult the return to the village and also increase the exposure of swiddeners to malaria.
- c. *Collectors of forest products.* These activities are mostly done by individuals or small groups of people who cover wide areas, following more

or less fixed itineraries. They gather periodically in fixed trading posts to sell their collection and purchase their necessities, including medicines. The stay in these trade posts presents a higher risk of acquiring malaria than the stay in the forest, if they remain mobile and isolated. Antimalarial programmes have normally established “case detection agents” in these posts. Their collection of blood slides has often given the impression of high malaria endemicity in wide areas of forest.

- d. *Gold and gem mining.* These constitute the most severe and destructive forms of aggression to forest ecosystems and present at the same time the most serious problems from the point of view of malaria epidemiology and control. The population of mining labourers is made up of people of very varied origins who migrate frequently between old and new mining areas; they generally establish small settlements, made up of the simplest type of shelters that offer little or no protection against local vectors. These settlements may grow explosively if a rich vein of mineral is discovered and attract drug vendors and medical practitioners, as money is relatively abundant; thus malaria control is based almost exclusively on the use and abuse of antimalarial medicines. These areas have been and continue to be major sources of resistance to antimalarials.
- e. *Police and army posts in forest areas.* These posts are often manned by people on temporary assignment from areas with lesser malaria risk. It is important to maintain them in good health to enable them to perform their duties uninterruptedly. They are therefore under continuous chemoprophylaxis with the most effective and often the newest antimalarial medicines. In this context, they are like the workers in economic development projects and the miners. But of the three groups they are the most likely to observe a schedule of chemoprophylaxis. They may also be the most accessible for the introduction of personal protection and/or vector control.
- f. *Illegal activities and rebel groups.* In many forest areas of South America and Asia there are more or less organized groups engaged in socio-political revolt or in a wide range of illegal activities, from smuggling to drug cultivation and trade. Although these groups are out of reach of normal governmental action, it has to be recognized that they are in more or less close contact with the more settled population and are part of the malaria epidemiological ecosystem. Malariologists should try to evaluate their situation and epidemiological and social linkages and ascertain the possibilities of providing help and guidance, no matter how indirectly.
- g. *Workers in economic development projects.* Historically these have constituted the most acclaimed successes of malaria control. In the first quarter of the 20th century, the construction of the Panama Canal, the

rubber plantations in Malaya, the railways in South-East Asia, Africa and South America were among the most successful and famous malaria control programmes in the tropics, thoroughly planned, well administered, funded and rigidly executed. Modern projects, like the construction of the transamazonian highway in the 1970s or a number of dams in tropical forest areas with a very high malarious potential, have been completed without major malaria problems, thanks to the adoption of similar sanitation and personal protection discipline as was developed by classical malariology.

- h. *International border posts.* Many international borders in the tropics run across forests, often following important rivers. Economic activities across borders, legal or not, are always intense. Often forest border areas permit easy access to more economically active countries by undocumented migrant labour, while they also constitute refuge for rebels and other persecuted individuals, most of whom may remain highly mobile and be exposed to relatively high malaria risks. Some border areas harbour recognized refugee camps for displaced populations, which may be considered as part of this eco-epidemiological type. As, in many forest areas, rivers may constitute the main lines of communication, at least for non-native populations. It is mainly along the rivers that trade and government posts, including health care facilities, have been established. Countries enjoying more developed or accessible medical care will, in addition, attract patients from across the border who may be only merely seeking better care. All these factors result in a considerable increase of registered malaria incidence in border areas.
- i. *Forest fringe areas.* These are often a dynamic transition from the forest to neighbouring savanna where progressive advance of deforestation turns forest fringes into wide areas in which agriculture and pasturelands alternate with more or less large areas of forest. Agriculture spreads rapidly along highways and around main communication nodes, towns or government centres, leaving in between islands of forested hills and river courses, unless the latter have been invaded by gold miners, in which case they are left as broad arid scars, without any vegetation. Villagers in forest fringe areas may be engaged only in agricultural activities or cattle breeding, and more or less temporarily in activities in the forest, such as swidden agriculture, hunting, fuel or food gathering for village consumption, or mining, lumbering or other major economic enterprises. The malaria exposure is dependent on the amount of time spent on each activity, the type of shelter and camp, as well as the methods of protection used. It should be noted that the distribution of activities may rapidly change if a “diamond bomb” or a “vein of gold” is discovered in the nearby forest, creating a rush towards mining and

consequent malaria resurgence. One of the most dramatic and recent such episodes has been the gold rush in Mato Grosso, Brazil, in the early 1990s. It is important to ascertain the situations of high malaria risk in order to design appropriate control action. Age and gender distribution of malaria patients, including relative incidence of *P. falciparum* and *P. vivax*, may give an indication of whether transmission occurs in the villages or it is limited to certain population groups involved in forest activities with or without important involvement in forest activities, the former showing much higher parasite rates, sometimes exclusively among adult males.

5.1.3.2 Vector control issues and challenges

IRS is relatively ineffective against the highly exophilic forest vectors, not only because of the resting habits of the vectors, but because the incomplete temporary shelters frequently do not have walls to be sprayed, and because the mobility of settlements, which remain unreported and inaccessible. It has to be recognized that, in the most stable agricultural communities, well-organized spraying operations with sufficient logistical support were able to reduce malaria transmission, as in the Bolivarian Republic of Venezuela (Lengüeta de Barinas) in the 1970s and in pilot projects in Malaysia and elsewhere. Nevertheless, such efforts are often unsustainable or less cost-effective.

Protection has been traditionally dependent on the use of antimalarials, mostly as chemoprophylaxis, in an organized and disciplined manner in well-administered development projects and military or police posts, and, in an often excessive, irregular and ineffective manner, in spontaneous colonized sites and mining or refugee camps. It is important, therefore, to improve the diagnosis and treatment of fever, facilitate referral, establish and support relevant information systems and improve the monitoring and management of resistance to antimalarials, everywhere. It is equally important to improve the selection and utilization of personal protection measures, including at least the following:

- a. chemoprophylaxis should be always complemented with measures aiming at reducing human-vector contact, such as the use of ITNs, IRS or larval control for relatively stable camps. Forces on long patrol missions should use treated mosquito nets over camp beds and hammocks, supplemented by the use of repellents. The exclusive dependence on chemoprophylaxis should be discouraged.
- b. new tools are under development for prevention of forest malaria such as tarpaulins incorporating insecticides, long-lasting treated hammocks and hammock nets, long-lasting treated blankets or bed sheets. They are

being tested in various epidemiological settings. Used alone or in combination, these tools may improve the prevention of forest malaria in the near future.

It is also important to:

- a. sensitize the general public and the local authorities about the ravages of malaria on the health of native forest populations and the need to collaborate in the preservation of their environment, while ensuring accessibility to health care and education facilities;
- b. strengthen and diffuse mechanisms of public information about the existence of health care posts open to everybody, in order to reach population groups who may be reluctant to use public health services;
- c. ensure that malaria workers and other health staff recognize the importance of information about new economic activities in their areas of responsibility, as well as population movements and occurrences of fever outbreaks, which should require immediate reporting and investigation;
- d. promote and support epidemiological and entomological research into the ways of penetration, attraction factors and mechanisms of adaptation of forest vectors to human hosts and shelters, as well as the colonization of forest fringe tree plantations by forest vectors, such as *An. dirus*, in order to devise more effective preventive measures.

5.1.4 Highland and desert fringes

These two eco-epidemiological types represent the areas lying between the highly endemic areas and the deserts or high altitude areas with complete absence of transmission. These borders are in no way a continuous line. They form a wide band where endemicity progressively disappears, but where numerous islands of endemicity penetrate to non-malarious areas, following local availability of surface water in desert areas (oases) or high valleys, where the orientation and surrounding mountains provide a microclimate favourable for endemic or occasionally epidemic malaria. The main characteristic of these areas is the progressive increase of epidemic risk as endemicity declines. In highland fringes transmission potential is mainly determined by temperature, and in arid or semi-arid desert fringe areas availability of surface water and ambient relative humidity play the major roles. Populations in these areas lack sufficient immunity to the disease as the result of low levels, or absence, of transmission in normal circumstances, so that severe epidemics may occur when meteorological conditions favour malaria transmission.

5.1.4.1 Malaria vectors and transmission

Malaria vectors in foothills and medium altitude valleys are more efficient than in the plains in South and South-East Asia (e.g. *An. fluviatilis* and *An. minimus*), while the opposite is the case in Central and South America (*An. pseudopunctipennis*). Desert fringe areas share with neighbouring savannah or plains those vectors, such as *An. arabiensis*, which are more adaptable to dry conditions.

The term “highland” is a rather relative term, depending on latitude, in view of which highland malaria has been defined as “malaria occurring at the local altitudinal limits of transmission”. Although altitude is known to be an important determinant of malaria endemicity, average minimum night time temperature is perhaps the most important factor involved, due to its effect on the duration of the sporogonic development of the *Plasmodium* parasite within the *Anopheles* vector, as well as the development and survival of the vector itself.

Desert fringe areas, on the other hand, are mainly located in warm lowland areas. In most of these areas, malaria transmission is dependent on availability of surface water and the associated increased humidity. However, temperature may be a determinant factor in the hot and dry climate detrimental to both the vector and the parasite; oasis malaria is characterized by the fact that in summer very high temperature and low relative humidity shorten vector survival, while in winter low temperature prevents parasite development, transmission being thus limited to the spring and autumn periods when both temperature and humidity are suitable. Short seasonal transmission is possible in most of these areas, especially during and after the rains when the ambient temperature decreases and humidity increases, conditions that are favourable for the survival of the vectors and the parasite. Abnormally heavy rainfall causing flooding almost always gives rise to malaria outbreaks in desert fringe areas. Monitoring of rainfall in these areas can, therefore, provide a fairly accurate forecast of malaria transmission risk.

Malaria transmission in these two eco-epidemiological types is reduced and interrupted as the adverse conditions (temperature in highlands and surface water/relative humidity in desert/arid areas) become extreme. Transmission is thus reduced in these areas to a short season (decreasing with altitude or aridity), with areas where transmission only occurs in abnormal years with exceptionally long warm periods or high rainfall. These areas are therefore epidemic-prone and the risk of malaria transmission shows great spatial and temporal variation. Epidemics are generally superimposed over the seasonal increase, hence making early detection of abnormal situations difficult.

5.1.4.2 Vector control issues and challenges

Malaria control in many of these areas still depends to a great extent on routine use of IRS, which is often poorly targeted. Most highland and desert fringe areas have seasonally limited malaria transmission and a very marked variation in malaria risk from year to year. In many cases, the low survival rate of vectors resulting from the hostile outdoor environment means that high anopheline density is required to sustain transmission. In highland and desert fringes in Africa, *P. falciparum* is the dominant species, but outside Africa, *P. vivax* generally dominates, although there are also *P. falciparum* infections in many of these areas. As the result of low transmission levels in normal circumstances, little or no immunity is developed against the disease; hence, all age groups may be affected by epidemics.

Vector control is an important tool in these areas to protect the population from seasonal transmission and occasionally severe malaria epidemics. It should be noted that nearly all available vector control options can have an impact in these areas, although their effectiveness and ease of implementation vary according to ecological characteristics of the target areas. The choice of appropriate vector control options depends on the local vector behaviour, cost and other socioeconomic considerations.

There is a need for improving the choice of vector control interventions based on a better knowledge of local epidemiology and epidemic risk. Ideally, IRS should be used just before the transmission season, although operational and financial problems often lead to delays, causing spraying to lose a great part of its effectiveness.

ITNs are being promoted in most areas, although coverage remains generally low. Circumstantially, areas with low malaria transmission usually lack mosquito nuisance for much of the year, limiting the appropriate use and acceptability of ITNs by the population.

Larviciding, source reduction and the use of larvivorous fish may be effective if the breeding sites of vectors are limited and well known. Such anti-larval measures are relatively more important where the vectorial capacity is high.

Other specific measures include zooprophyllaxis and intermittent adulticidal space-spraying. In some areas, ground applications of malathion or pyrethroid space-spray has been applied effectively against outdoor-resting *An. culicifacies* as a supplement to IRS. Thermal fogging with malathion from vehicle-mounted machines has become quite widespread in cities as an anti-malaria measure, but its effectiveness against indoor-resting mosquitoes was found to be universally poor.

Vector control interventions are important for preventing or reducing transmission in epidemic-prone highland fringe and desert fringe areas, but their selective use and timing should be based on local epidemiological conditions and risk of transmission. In such situations, where the community may have low immunity to malaria, IRS is the most widely used and very effective method of epidemic prevention.

The main challenges facing IRS include: insufficient local capability for implementation of vector control; lack of reliable malaria early warning systems for accurate targeting of areas with greater transmission risk; limited number of cost-effective and safe insecticides; physiological and behavioural resistance to insecticides; economic activities resulting in man-made environmental risk factors; inadequate community participation. In southern Africa, for example, effectiveness of IRS in some countries was not only constrained by a marked resistance of *An. arabiensis*, but first and foremost by considerable social resistance of the local populations due to intense biting by soft ticks and bedbugs biting spree (caused by DDT irritability), the whitish marks left on inside walls after spray, and a suffocating DDT smell inside sprayed houses. These were followed by strong political pressure brought about by the anti-DDT campaign.

Larval control measures may be considered in areas where aquatic sites are well-defined, as in valleys and desert fringe areas, but their use requires an improved knowledge of local epidemiology and ecology. Yet, elimination of breeding places in arid zones is known to have a dramatic impact on transmission levels.

While research to develop epidemic early warning models is underway, it is recommended that available knowledge be used to stratify areas according to transmission risk, and to take preventive vector control measures in areas where risk factors are known. In desert fringe areas where the risk of transmission is determined by availability of surface water, decisions regarding preventive measures such as IRS may be made with relative ease, especially following heavy or abnormal rainfall. The use of IRS for the control of malaria epidemics requires early detection, and thus strong disease monitoring systems are required if timely vector control measures are to be taken. Use of expensive measures such as IRS should be based on the expected length of the transmission period and the spatial extent of affected areas.

- ***Options for epidemic-prone areas with little or no transmission***

Taking preventive vector control measures in epidemic-prone areas would require a reliable early warning system. Vector control is important for the control of epidemics that have been detected in their early stages of development, and for epidemic prevention following identifiable alarm signals

from early warning systems, when these exist. However, the first priority in the acute stage of a malaria epidemic should always be the improvement and extension of facilities for prompt and effective diagnosis and treatment of people with malaria and mass fever treatment to reduce the parasite reservoir within the human population.

Vector control requires preparedness in terms of human and logistic resources as well as a good disease surveillance system to detect abnormal situations as early as possible. Unfortunately, vector control during epidemics is often ineffective because it is implemented too late, determined by political and not technical considerations, and carried out with inadequate preparation and planning. Nevertheless, if resources allow and when transmission is likely to continue for a few months, it may be advisable to carry out selective and targeted vector control measures such as IRS, provided these interventions do not negatively affect the priority to effective case management.

Capacity at district and peripheral levels should be enhanced to ensure that surveillance data are recorded, analysed and interpreted appropriately for early detection of epidemic events. There is also a need for developing the logistic capacity of malaria control programmes and district health teams in terms of equipment and other supplies for vector control.

The use of ITNs may be promoted in these areas before and during epidemics, but are unlikely to be practicable as an emergency measure replacing other methods. The use of larval control measures has little impact in most rural highlands, as well as in rain-dependent outbreaks in arid areas, where vector breeding places are numerous and usually inconspicuous. Measures targeting the aquatic stages of vectors should be considered only when anopheline breeding sites can be identified, particularly around settlements. This requires sufficient expertise to identify specific *Anopheles* sources and the risk of increased transmission.

- ***Options for highland or desert fringe areas with seasonal transmission***

It is useful to look closely at factors that constitute a targeted application of IRS in these areas. Annual spraying may prevent the occasionally severe malaria epidemics that are often superimposed over seasonal increase. The very unstable nature of malaria and its significant inter-annual variation in such areas also results in below normal and even absence of transmission during some periods. Regular spraying may therefore represent unnecessary wastage of often scarce resources. The level of malaria incidence at health facilities during the previous transmission season has been sometimes used as a rough guide for the decision-making process, although it may be very misleading. It has been observed that malaria control programmes sometimes target areas affected by epidemics in the previous season at the

expense of others with more likelihood of intense transmission. Nevertheless, incidence at the start of the transmission season, especially towards the beginning of the rainy season, may be used in some areas as a good indicator of an intense transmission towards the end of the rainy season.

In oasis malaria and some arid areas where transmission may increase with increased humidity without significant local rainfall, there are usually well-defined mosquito breeding sites (e.g. irrigated cultivation with water from wells) which make larval control feasible through environmental management, larviciding or biological control.

In addition to the use of larvicides such as temephos in breeding sites, larvivorous fish have proved to be effective in wells and cisterns in arid areas. A randomized controlled trial in the Red Sea port of Assab has shown that an indigenous fish, *Aphanius dispar*, was highly effective in controlling the local malaria vector, *An. culicifacies adenensis*, in cisterns, wells and barrels (31). Similarly, in the Ogaden desert in south-eastern Ethiopia, the use of the local species *Oreochromis spilurus spilurus* provided an effective larval control measure that could be applied through community participation (32).

Zooprophylaxis may be considered in some arid areas and is often used for mosquito protection by nomads. Although zooprophylaxis has been promoted as a protective measure against mosquito bites, frequently the presence of cattle in homesteads tends to increase the human biting rate of zoophilic vectors, but keeping cattle in separate sheds outside human dwellings tends to reduce human biting and malaria transmission (33). This is particularly so where the human-cattle ratio is high (34). Several studies suggest that animals are only likely to have a worthwhile prophylactic effect when the vector is zoophilic, and then only when the animals are deployed to form a barrier between that vector and humans (35). In situations where deployment of such a “zoobarrier” is impractical, livestock should be located as far from humans as possible.

5.1.5 Wetland and coastal areas

Coastal areas around the world offer particularly favourable conditions for malaria transmission. Efficient vector species thrive in brackish water or wetland habitats, and coastal areas are often attractive to a variety of human activities. Furthermore, coastal areas are increasingly attractive to tourist development projects and many important cities and towns are located in coastal areas. Both types of agglomerations are often able to mobilize important resources to undertake major environmental management works.

5.1.5.1 Malaria vectors and transmission

Classic studies on the *An. maculipennis* complex in Europe first showed how the most important vectors, *An. atroparvus*, *An. labranchiae* and *An. sacharovi*, were associated with coastal ecotypes, whereas the lesser vector species and non-vectors were associated with various other habitats. Similar differences of vectorial capacity between coastal and other members of such complexes of sibling species still exist. The *An. subpictus* complex and the *An. sudaicus* complex in South-East Asia and the *An. punctulatus* complex of the Australasian region are good examples. The situation is reversed among members of the *An. gambiae* complex in tropical Africa, where the coastal species *An. melas* in West Africa and *An. merus* in East Africa are lesser vectors than the freshwater species *An. arabiensis* and *An. gambiae* across the Afrotropical region. In the Neotropical region, some efficient malaria vectors are associated with coastal brackish water habitats, notably *An. aquasalis* and *An. albimanus* in South America and *An. albimanus* in some areas in Central America.

Important factors in coastal malaria transmission include:

- a. *Demography and population growth.* Over the last 50 years, the population in Asia and Oceania has almost doubled, growing by more than 43.7 and 0.35 million each year, to the present level of over 3672 and 31 million, respectively. As the population continues to grow, people move away from the countryside to the cities and low-lying coastal areas, attracted by the hope of a better life. It is currently estimated that about half of the global population lives in coastal zones, although there is large variation among countries.
- b. *Environment and land-use.* Low-lying coastal areas with *Anopheles* vectors that breed in freshwater and brackish water are common in malaria-endemic or receptive countries in the Western Pacific Region and Neotropics. Increase of vector population may be explained by the changes in land use or human disturbance of the environment such as aquaculture, resulting in the accumulation of stagnant, brackish water. Such disturbances can greatly increase the risk of transmission in coastal ecotypes. Conversely, well-designed environmental management can reduce this risk in coastal areas, and desalination schemes carried out to improve agriculture can have a similarly unintended beneficial side effect.
- c. *Human behaviour.* Human activities or behaviour that influence malaria incidence in coastal areas and wetlands include siting of residential areas in close proximity to extensive tropical wetlands or brackish lagoons, creeks or deltas, the time people retire to sleep, use of preventive meas-

ures, willingness to seek treatment, motivation to mosquito-proof houses, and compliance with treatment and prophylaxis regimens. Behaviour interacts with migration, health services, education, and specific malaria control activities in complex ways.

- d. *Economic development, security and social organization.* Coastal zones are characterized by a rich diversity of ecosystems and a great number of socioeconomic activities. Equitable development with improvement of education, health services and income can potentially reduce migration due to economic hardship or political instability. It is associated with improved preventive and curative services, better knowledge about how to avoid malaria, greater certainty that needed curative care is affordable, better housing, decreased family size, and decreased malaria risk. Conversely, economic and political breakdown, civil or ethnic conflict and warlike activities usually have the opposite effects.
- e. *Climate change has potential effects on coastal malaria.* Firstly, more frequent cyclones and floods will increase vector density and the risk of malaria. Past epidemics were often associated with above average rainfall. Second, flooding of low-lying areas, due to raised sea levels will expand breeding areas. Within the Asia-Pacific region, many such areas are malarious and refugees from them could provide a large reservoir of infection. Emergency relocation of refugees, particularly if aircraft, trains and/or buses are used, will increase the possibility of introducing exotic vectors into malaria-free countries. Parasites resistant to antimalarials will add to the difficulties of treatment. More than direct land loss due to seas rising, indirect factors are generally listed as the main difficulties associated with the rise in sea level. These include erosion patterns and damage to coastal infrastructure, salinization of wells, suboptimal functioning of the sewerage and drainage systems of coastal cities, with resulting health impacts, loss of littoral ecosystems and loss of biotic resources.

5.1.5.2 *Vector control issues and challenges*

The current major prevention and control interventions used in coastal ecotypes by the national malaria control programmes and the stage at which they exert their effects are basically:

- a. ITNs;
- b. limited IRS with stable insecticides;
- c. larval density reduction by chemical, biological or physical methods.

Coastal areas often require a combination of measures, which in towns and in areas of economic importance may include measures of species sanita-

tion, such as the desalinisation of large areas of the Mekong delta to control *An. sundaicus*, or the use of pipelines to allow the exchange of ocean water with lagoons to increase the salinity above that tolerated by vectors breeding in brackish water, as in the case of *An. farauti* in the Honiara area of the Solomon Islands.

Nevertheless, important challenges remain, including:

- a. expansion of urban areas adjacent to remote seashores with thick vegetation and large mosquito populations, where the application of standard vector control measures may be difficult. Vectors are often early-biting and exophilic, reducing the effectiveness of both IRS and ITNs;
- b. frequently larval habitats are numerous and small and are not amenable to source reduction. Source reduction by villagers is dependent on their knowledge of larval habitats and their ability to differentiate between anopheline and culicine larvae, which is usually not being taught to them;
- c. source reduction or environmental manipulation is dependent on a knowledge of the factors which affect the bionomics of the local vectors, while the extrapolation of measures designed elsewhere may be counter-productive; for example, the coastal vectors in many areas of the Western Pacific and South-East Asia are sun-loving and some of the activities being sometimes advocated, such as deweeding swamps, could enhance their numbers;
- d. environmental manipulation (or modification) is costly and often depends on imported hardware for initial investment and on a good infrastructure and management for monitoring and preventive maintenance;
- e. community participation is being sought but the implementers (malaria control personnel) in many cases have no training in community participation, hence they are confronted with difficulties in convincing community members to participate in larval control. Awareness campaigns need to be participatory and community-friendly.

5.1.6 Urban and peri-urban areas

Tropical, urban areas generally have a lower malaria incidence than the surrounding rural areas and often the centres of cities are free from malaria transmission. Nevertheless, practically all cities in malaria endemic areas accumulate a considerable number of imported malaria cases, as city dwellers may often be infected elsewhere and the medical services of the city attract people in search of treatment from a relatively wide rural area. This accumulation of “imported cases” tends to be biased towards severe

and drug-resistant cases, since city hospitals constitute the main referral level for neighbouring areas.

5.1.6.1 *Malaria vectors and transmission*

As tropical cities are far from being uniform, there are a number of cities with important malaria problems.

- a. These may be the result of transmission within the city by the same vectors as in neighbouring areas, because of the existence either within or in the periphery of the city, of areas which retain the ecological characteristics of rural areas and where, particularly in some cities with explosive growth, vector density and malaria transmission may be even intensified due to the increase of population density and the general neglect of the land; often this neglect results in such an increase of pollution that anophelines are replaced by *Culex* mosquitoes.
- b. A more serious problem may develop when the city creates favourable conditions for the establishment of an efficient malaria vector, as was the case of *An. sudaicus* in Calcutta's Salt Lake area or in the numerous open tanks in coastal cities in East India and Indonesia.
- c. A common feature of many tropical cities is the use of any unoccupied plot for the cultivation of vegetables or eventually rice, generally with informal irrigation and no proper drainage, thus creating favourable breeding places.
- d. Finally, there exists what can be considered urban malaria *sensu stricto* that is transmitted in the city by vectors specially adapted to the urban environment. The clearest example of this is the adaptation of *An. stephensi* to breeding in wells, cisterns, roof gutters, tanks and all kinds of containers in many Indian cities; when such conditions occur in a large crowded city it can produce a severe epidemic as happened in Mumbai in the early years of the twentieth century or in Karachi in 1967. Similar adaptations have occurred elsewhere, e.g. *An. claviger* in cities of Israel, Lebanon and the Syrian Arab Republic breeding in underground cisterns and other water storage systems, and *An. arabiensis* on roofs in Mauritius and La Réunion Islands.

5.1.6.2 *Vector control issues and challenges*

Vector control in urban areas may be haphazard, often biased towards the control of nuisance mosquitoes in residential areas, and influenced by past strategies of malaria control, such as the belief that malaria in towns could be prevented by barrier spraying of the periphery of towns, even if, as discussed above, islands of transmission may occur in central areas.

IRS is still widely used in peri-urban areas. The acceptability by the population continues however to decline, even if water-dispersible powders are avoided and pyrethroids used which do not leave the objectionable marks of other insecticides because the required dosages of modern pyrethroids are very low.

Individual and family protection measures, such as the use of mosquito nets, have always been popular in areas of high mosquito infestation, and the abundant culicine densities in many urban areas are often such a nuisance as to induce people to spend substantial amounts of money on domestic pest control.

ITNs obtain considerably higher coverage in urban areas than in rural areas in many malaria control programmes which are adopting ITNs as their main malaria prevention measure. Acceptability is, as in rural areas, very variable and, besides the density of nuisance mosquitoes, is influenced by the climatic conditions, price, sense of privacy, status, etc. In many areas high demand of ITNs has been dependent on their high effectiveness against domestic flies, *Culex* mosquitoes, bedbugs and lice, and this demand may disappear when these pests become resistant to pyrethroids.

Larval control is particularly indicated in urban areas, where most breeding places are man-made and can be identified, mapped and treated, and actual malaria transmission is often localized and, at least in principle, easy to control. Larviciding is often indicated using all kinds of larvicides, from oiling of waste water collections to temephos or Insect Development Inhibitors (IDI) for clean waters, and larvivorous fish for ornamental waters.

Environmental sanitation constitutes the most effective and sustainable measure of mosquito control. Implementation of community-wide environmental sanitation requires the mobilization and commitment of important community resources in urban environments, not only for undertaking necessary engineering works, but also for promoting, supporting and coordinating individual action. It is therefore essential that such actions be carefully planned and based on a sound knowledge of the local epidemiology and the bionomics of the vectors. It is necessary to ensure the continuous availability of professional entomological and engineering competence for the planning, execution and evaluation of sanitation projects; many of the towns in the tropics are growing so rapidly that drastic changes in the epidemiological situation may occur between the time of planning and execution.

Domestic and peri-domestic sanitation may be an important component where individual and community cooperation is essential. It often requires legislation and enforcement, but above all public information and education. For example, in the case of *An. stephensi* in urban areas of the Indian

subcontinent, breeding in clean water containers inside houses will require their careful protection or periodic drainage. Legislation and enforcement will be required to prevent or control the creation of man-made breeding places, such as urban irrigated agriculture or borrow pits.

The following control activities should be coordinated with related activities of municipal and other authorities:

- a. integrated vector management activities, including focal IRS or ITNs in problem areas; bylaws enforced on growth of irrigated crops in the urban area and screening of overhead water tanks against *An. stephensi*, as well as improvement of houses to make them more mosquito-proof;
- b. larviciding;
- c. source reduction and improved drainage.

It is important that project management personnel be fully aware of the distinction between anti-malaria activities and nuisance mosquito control.

5.2 Situations of rapid development change

5.2.1 Agricultural development projects

There are many well documented instances of heavy malaria burdens in agricultural communities during the past century, especially in newly established irrigated agricultural systems (36). Such systems seem to generate high disease burdens through the interplay of bio-ecological, socioeconomic and political factors such as high vector densities, resistant strains of parasites and vectors, human aggregation and migration, poverty, ignorance, inadequate physical and trained human resource infrastructure to provide adequate preventive and curative care, and violent political unrest.

5.2.1.1 *Malaria vectors and transmission*

Malaria vectors in development projects are normally the same as in neighbouring areas, although in some cases differences in species distribution and succession are observed, and malaria transmission may differ considerably due to the local environmental modifications and the changes in population distribution introduced by the project.

Agricultural development projects undergo temporal evolution, and this progression impacts on malaria and malaria control. In spite of pronouncements to the contrary, health generally remains low among developmental

priorities at project planning and execution, which is driven primarily by the engineering, agricultural and macroeconomic sectors. Settlers are moved in when agricultural/irrigation/administrative infrastructure are complete. Health infrastructure usually lags behind, by 1–2 years or more. Even if health services are provided for project personnel, the employment opportunities offered by the project generally attract considerably more people than the project is able to employ and eventually to settle; these people remain highly mobile and survive mainly through the provision of legal or illegal temporary services. Compounding the problem is that settlers themselves may come from varied epidemiological backgrounds – some from malaria-endemic areas with some degree of acquired immunity, and others from non-endemic areas and completely immunologically naïve. At project inception, therefore, one often has a situation of a poor, vulnerable community usually living in temporary housing, under physical, emotional and economic stress. With few personal economic resources or community organization or supporting health infrastructure to combat the disease, malaria affects such communities severely. At this stage, occasional clinics or residual spray campaigns do little to alleviate the problem.

Generally, after a few years, some form of health infrastructure becomes established within or in close proximity to the agricultural development area, so there is reasonable access to health care. Settlers have constructed permanent abodes of varying qualities that afford some protection against mosquitoes – usually houses constructed out of mud and thatch (or similar “natural” materials) are more attractive to mosquitoes than those constructed of brick, cement, metal or asbestos components. Location of housing also has important implications for malaria vectors – those situated close (usually less than 1 km distance) to permanent or seasonal vector breeding habitats can be more vulnerable than more distant communities. Crop type, cropping cycles, irrigation rotations within a cycle, livestock types and shepherding strategies can all impact on vectors and thereby disease. Socioeconomic differences within communities make some more susceptible than others in terms of economic capacity to combat the disease. Moreover, as a project develops, it attracts temporary workers who are considerably more exposed than the settlers.

Social organization and gender roles also impact on malaria, as does knowledge on health and sanitation issues in general, and malaria transmission in particular. The system moves from a situation of almost uniform vulnerability in the early period of the project to one of differential vulnerability due to a complex interplay of some of the factors outlined above. Usually, economic development both at individual and system level is accompanied by a decline in malaria incidence – again, the reasons are complex, but better housing, improved nutrition, more resources to combat the disease at

a personal/family level, and better health support infrastructure are certainly important. However, the most affected segments of the community often remain trapped in a virtually unending poverty-malaria vicious cycle.

5.2.1.2 *Vector control issues and challenges*

IRS and, more recently, ITNs are the major vector control measures in use over the past 50 years. In many large agricultural production (especially irrigated) systems, effectiveness has been limited by lack of resources (trained manpower, spray equipment, insecticide), and poor organization and coordination between the health and agricultural sectors, especially in the early stages of project implementation. The involvement of communities in identifying and prioritizing their health problems, making information on different control options available, and facilitating the reaching of consensus in tackling the problems is an essential investment for successful and sustainable implementation of strategies such as ITNs in an agricultural scenario where complexities related to social structure and activity patterns related to agricultural practices play a major role in the lives of farming communities.

Chemical larviciding as a means of malaria vector control has a potential application in agricultural development projects and irrigated agriculture; it has a long history in areas where some vectors breed in specific habitats such as water reservoirs, flowing or pooled streams and other waterways (including irrigation canals). Although effective, biological control agents such as *Bacillus thuringiensis var. israeliensis* (*Bti*) are not used on a large scale in malaria control. This is due to cost, and also to operational considerations, the manpower requirements to deliver these on the ground to the myriad potential breeding areas within a system being prohibitive. In most areas, nevertheless, larval control is at best secondary to IRS or, increasingly, ITNs as a vector control strategy. The main problem is insufficient knowledge on vector breeding ecology and its biology at a local level so as to effectively target larviciding both spatially and temporally.

Similar limitations apply to environmental management aimed at reducing breeding sources, even in areas of unstable and seasonal transmission, and often localized breeding habitats. However, these methods should be reconsidered even in Africa, especially in situations of seasonal transmission where opportunities to reduce transmission may be available. Flushing of canals, intermittent irrigation and other waterways have been frequently advocated, and sometimes implemented, but only in a few tropical areas on a sustained basis. Unless water is plentiful, well stored and regulated, flushing is a difficult option to implement operationally.

There seems to be more potential for water management in agricultural fields, especially rice fields, where intermittent or rotational irrigation (also known as “alternate wet and dry irrigation” or AWDI) can be practised. There have been many AWDI trials with varying degrees of success (37, 38), but most have been in experimental plots where agronomic aspects have been under the control of the experimenters. In China, however, large-scale application of the AWDI technique has been held responsible for significant reductions in rice field breeding vectors and malaria.

Personal protection through mosquito coils and indigenous materials (oils, smokes, etc.) is widely practised in agricultural communities but is of doubtful effectiveness in terms of protection against transmission, although it often provides some relief from the “nuisance” aspect in situations of high mosquito (including vector) biting densities. Commercial repellents are generally too expensive for poor farmer communities.

Some of the general constraints facing malaria vector control may be overcome in agricultural systems, which offer opportunities for organizing vector and malaria control in partnership with the agricultural and irrigation sectors, so as to exploit some of the resources of such systems.

Development projects may actually offer some opportunities for optimizing vector control and personal protection, for example by:

- a. proactively including health care in general and malaria control in particular into the operational framework of new agricultural projects. In relation to vector control, this would need to be from project inception itself, to initially protect construction staff at all levels, and then to extend it to settlers as they arrive;
- b. using the agricultural extension system in established agricultural systems to increase vector control outreach in difficult areas without health infrastructure, through the training and equipping of agricultural extension personnel;
- c. exploring with agricultural and irrigation authorities, and the farming community, environmental management methods such as source reduction, water/land management or other appropriate engineering measures to reduce the opportunities for vector breeding in different components of the agricultural system;
- d. using the techniques of special programmes such as integrated pest management (IPM) for social mobilization. IPM has strong field-based farmer learning techniques propagated through farmer field schools that can be used to disseminate health messages and interventions. The increased knowledge and awareness (through their own learning and experience) then sets the stage for a range of actions, from community

- cooperation with spray teams to community mobilization for net re-treatment when the chemicals are provided, to community willingness to implement environmental management techniques on-field where appropriate;
- e. using secondary malaria information within the health system, allied with land use, meteorological, topographic, demographic, and socio-economic and any other potentially relevant information specific to a given agricultural system, using GIS technology to generate risk maps and risk analyses that can be used by health and agricultural managers to target vector control. This desk-top exercise can be followed up by on-field exploration to determine key aspects such as vector breeding potentialities, location of communities, house construction, etc. of intermittently and/or consistently “high risk” areas and devise control strategies appropriately;
 - f. developing a more flexible and targeted mix of control options specific to different parts of an agricultural system that may pose differential risks for malaria as demonstrated by simple analysis of health systems information or risk mapping.

5.2.2 Socio-political disturbances

Context-specific factors giving rise to high malaria burdens in complex emergencies include breakdown of health services, concentration of non-immune refugees in malaria risk areas, malnourishment, siting of refugee camps on marginal land prone to flooding or vector breeding, and problems in gaining access or supplying medicine to the displaced population. Conventional malaria control strategies need to be adapted to refugee situations accordingly.

As conflict progresses, complex emergencies usually evolve from acute emergency to post-emergency phases. The acute phase is characterized by sudden population displacement from the areas of disturbance and high mortality rates, and may last only a few months. During the post-emergency phase, as refugees re-settle, the health situation is generally brought under control and basic needs are met. Chronic emergencies are characterized by political deadlock which may last many years; conflict areas of the country stay locked in an acute phase while other areas may progress towards post-conflict stability. What can be achieved in malaria control will differ according to the phase of the emergency and local circumstances.

Disease management may not be a sufficient response to contain malaria in refugee camps. Personal protection and systematic vector control interventions should preferably be applied. Some control methods are suitable for

the acute phase, others for the post-emergency phase. The choice of intervention will depend on local factors such as the type of shelter available, human behaviour, and vector behaviour.

5.2.2.1 Acute emergency phase

Conventional control methods are most often used in acute and chronic emergencies where displaced populations inhabit some form of conventional housing and local vector species enter to feed and rest indoors. These include:

- a. IRS is most likely the intervention achieving the fastest reduction in malaria transmission, including in complex emergencies. However, if spray campaigns are delayed, high mortality may still result, and the campaign may be completed too late to have much impact. In long-term refugee populations where public health services are well funded and of reasonable standard it is possible to plan well in advance, anticipate insecticide requirements and provide the necessary training and supervision of spray teams required for good effect. For this reason, the most successful spray campaigns are generally done in post-emergency or chronic emergency conditions (39).
- b. ITNs are attractive to agencies and donors because they are technically simple and proven to be effective in stable settings. There are few documented examples showing that ITNs are effective in preventing malaria during acute emergencies. Admittedly, such evidence is very difficult to collect. In very insecure areas where a residual population remains behind but it is unsafe for agencies to penetrate or move around, no other form of personal protection may be practicable, and distribution of ITNs, preferably LLINs may seem the best option.
- c. For refugee populations or internally displaced populations living outdoors under tents or plastic sheeting there is insufficient space for supporting ITNs. However, there are ways of hanging ITNs outdoors, and ITNs might be used in such situations by people who traditionally sleep in the open in hot weather. The treatment of inner surfaces of tents with residual insecticide has also been practised in some situations in refugee camps. The half-life of ITNs in an emergency situation may be less than one year. Agencies should exercise caution, and consider alternatives, before embarking on a major ITN campaign from the very outset of an emergency.
- d. Rapid implementation of residual spraying can be completed after the acute emergency phase by distribution of ITNs, preferably LLINs, which refugees can subsequently take home.

Novel approaches as alternatives to IRS and ITNs in the acute phase have shown promising results, particularly:

- ***Insecticide impregnated tents and tarpaulins***

A common technical problem in any new refugee camp is the absence of conventional surfaces for insecticide treatment, such as walls and ceilings of houses. Where plastic sheeting or canvas tents are issued to refugees, spraying of inner surfaces with a residual pyrethroids, preferably a water-based suspension concentrate, has been shown to give a year-long protection against malaria vectors (40). Residual activity lasts longer if the tent is double sheeted. Blankets and shelter materials (plastic tarpaulins) are always distributed as part of the emergency response and these materials may constitute the only surfaces suitable or readily available for insecticide treatment. In recent years plastic tarpaulins have tended to replace canvas tents as the favoured shelter material for refugees, being cheaper to produce and air freight. Roll Back Malaria has been working with industry to develop long-lasting insecticide-impregnated plastic tarpaulins (ITPs). Deltamethrin treated tarpaulins are currently being tested in refugee camps in West Africa.

A long-lasting deltamethrin-treated tent, made of polyester fibres, has recently been developed. Compared to ITPs, the tents are more comfortable and the level of personal protection obtained from their use might turn out to be greater. The cost is likely to be greater too. Unlike tents, tarpaulins may be used or erected in a variety of ways, combined with conventional housing materials and used as roofing or roofing underlays, or as wall coverings or door flaps. Some uses may not be effective for vector control and each situation should be examined in order to define appropriate use.

- ***Insecticide-treated blankets and top-sheets***

Another option in acute emergencies for refugees sleeping under plastic or other makeshift shelter is to treat their blankets or outer bed sheets with permethrin, an insecticide with repellent properties. A household randomized trial in an Afghan refugee camp showed 64% protection against *P. falciparum* infection and 38% protection against *P. vivax* infection for a period of three months among refugees less than 20 years old, and no side effects (41). Anopheline mortality and the reduction in bloodfeeding were both around 40%. This approach is practical because blankets are always distributed in acute emergencies, and treatment with permethrin would give protection under all types of shelter regardless of whether mosquitoes are endophilic or exophilic, endophagic or exophagic. The cost is only a fraction of that required for procuring ITNs. As in the malaria control trials, treated blankets showed equivalent protection to ITNs over the short term.

Permethrin and most probably etofenprox are the best insecticide to use on sheets/blankets because of their low mammalian toxicity and high repellency compared to other pyrethroids. Long-lasting treated blankets, based on the same technology as LLINs, are under development and testing.

- ***Insect repellents***

Insect repellents such as DEET (N, N-diethyl-3-toluamide) are widely used, especially by travellers in developed and developing countries for protection against mosquito bites. There is scepticism about their use as a malaria prevention measure, the assumption being that application to skin each night requires too much self-discipline for the method to be effective as a public health intervention. Some older trials failed to show any effect (42), whereas more recent interventions and placebo-controlled trials have shown a clear and substantial effect (43, 44). The advantage of skin repellents is their relative cheapness and the speed with which they can be freighted and distributed in an emergency. Some health education is certainly needed to make the link between protection against mosquito bites and malaria prevention. As a short-term measure in acute emergencies the use of repellents deserves further investigation.

5.2.2.2 Post-emergency phase

In the post-emergency phase refugees will progressively construct houses, allowing increased use of IRS or ITNs. IRS is primarily a community-protection measure and a mass effect on vector populations requires a majority of dwellings to be sprayed. When campaigns are well run, IRS is as effective as ITNs, as was demonstrated in comparative trials in refugee camps in Pakistan and the United Republic of Tanzania (45, 46). As a result of recurrent and/or annual activity carried out by UNHCR between 1991 and 1995, IRS campaigns targeting the more malarious camps reduced by two-thirds the overall malaria burden in the refugee population of the North West Frontier province of Pakistan. Over the long term, IRS campaigns are an expensive strategy because campaigns need to be repeated at least annually and recurrent costs remain high. If the emergency seems destined to continue for many years, ITNs are a more cost-effective and sustainable solution because recurrent costs for insecticide re-treatment are much less than for IRS (despite higher costs for net procurement). In camps where coverage is high, ITNs seem able to keep incidence at a very low level though, interestingly, they do not appear to be able to eliminate malaria altogether.

In the search for cheaper alternatives to ITNs and IRS that could be applied in chronic refugee settings, the treatment of domestic livestock with pyre-

throid insecticide has been introduced in Afghan refugee camps, with a good level of control. The technique should be considered in other areas where vectors are highly zoophilic.

5.2.2.3 Post-conflict phase

This is the stage where ITNs may have greatest potential because they provide returnees with a large degree of self-sufficiency. ITN users gain a degree of protection even if other members of the community are not using ITNs. The local private sector may not be able to meet the demand for ITNs. One approach is for a lead agency to coordinate the ITN programme and to provide training and ITNs to local NGOs working at community level. An NGO network may be the best way in the short term to achieve good coverage if public or private sector distribution systems are absent in the immediate post-conflict phase.

In summary, appropriate methods do now exist which can improve the situation at different stages of emergencies. Concerted application of these can have marked effect on transmission rates, and these need to be scaled up.

6. Health systems and malaria

Some perspectives, trends, and implications for malaria vector control and personal protection

The pervasive morbidity and high mortality of malaria persist because of failure of adequate contact between available preventive and curative health systems and those at risk of malaria transmission. The consequence is not just an intolerable burden for individuals, their families, and national health systems, but also a devastating and continuing impediment to socio-economic development. The paradox of a continuing, yet easily preventable, major cause of mortality raises important questions for policy makers and health systems.

In the analysis of current health system issues pertinent to malaria vector control and personal protection, the examples of IRS and ITNs will be considered.

6.1 Trends in global initiatives

Recent global health initiatives (Millennium Development Goals, 2000; United Nations Special Session on Children, 2002; Global Fund to fight AIDS, Tuberculosis and Malaria, 2002; WHO Three by Five, 2003) are increasingly disease-specific, narrow in technical content, short term-outcome oriented, and relatively silent on the role of a functional health system for delivery.

The pivotal role of health systems was recognized at the Abuja Roll Back Malaria Summit in 2000, which resolved in the Abuja Declaration “to initiate appropriate and sustainable action to strengthen health systems” to ensure the attainment of specific targets by the year 2005. The Abuja Declaration goes on to call upon Member States to undertake further *health systems reforms* necessary to support the stated goals.

6.2 Trends in local initiatives

At country level, there has been dramatic change in health systems over the past ten years, largely as a result of health sector reforms. These in turn were responses to general health system and health financing deterioration at the end of the 1980s provoked in most settings by macroeconomic constraints (47, 48) and, in some, by war and conflict (49).

Countries with high malaria burden are also among the poorest in the world (50). Such countries are almost all engaged in some form of poverty reduction strategy that should identify malaria as a priority. More importantly, efforts at poverty reduction have revealed even more starkly the rapidly widening gap between the poorest and the least poor within countries. Equity in both access to health interventions and in health outcomes is an overarching purpose of health development.

All of these changes at global and country level have important implications for how contemporary health systems can address malaria vector control and personal protection. In most instances these changes have not been fully exploited in terms of their potential to strengthen malaria control, and in some cases, malaria control has suffered as a consequence of such changes.

6.3 Health system dependency

There is no doubt that highly efficacious methods for malaria vector control and personal protection are available in the form, for example, of IRS and ITNs. Although technical innovations in both approaches continue to be made, in most settings both interventions are suitable, effective and comparably cost-effective.

Efficacy of these interventions is a measure of the maximum expected benefit (i.e. how well an intervention works under ideal conditions), while effectiveness is a measure of intervention performance in the routine health system (i.e. how well an intervention works under real-life conditions). The continuing burden of malaria in the face of efficacious methods means there is a problem with effectiveness, which in turn is a consequence of health system performance. Effectiveness is almost always less than the expected efficacy. The degree to which efficacy erodes to a lesser level of effectiveness is determined principally by coverage. However, coverage is composed of many dimensions. To understand this better it is important to disaggregate coverage into the following factors:

6.3.1 Access

The first and often most important step-down factor that reduces efficacy is the complex constellation of factors governing access. Access is basically the point of contact between the intervention and the household. IRS has to be delivered to the households. The same can apply to ITNs or the householder may have to go somewhere to obtain them. Access is often determined by operational dimensions such as geographic access, physical access, temporal access (seasonal, or time of day/week), and socioeconomic access (control of resources, gender).

6.3.2 Targeting

Once the connection between the intervention and the householder has been achieved, the second step-down is determined by the accuracy of the targeting by the provider. For example, if free ITNs or ITN vouchers are to be provided to households with pregnant women or young children, or if households at risk of epidemic malaria have been targeted for IRS, are such households correctly identified by the system? This is the equivalent of diagnostic accuracy for a clinical intervention.

6.3.3 Provider compliance

Assuming contact has been made between the service provider and the correct householder, the third step-down from expected efficacy is driven by the degree of provider compliance with the standard operating procedures (SOPs) for the intervention. The service provider may fail, for example, to prepare the proper dose of insecticide for IRS, or may fail to provide the ITNs as prescribed.

6.3.4 Consumer adherence

Once the system has delivered the correct intervention to the correct households, the fourth step-down in efficacy is determined by the degree of user or consumer adherence. A householder may choose to replaster recently sprayed walls, or may choose not to deploy their ITNs at certain times of year, despite a continuing risk of transmission.

It is easy to see how such realities could diminish the efficacy observed in research trials. If good efficacy can collapse so easily to much diminished effectiveness because of health system failings, clearly more attention needs to be paid to the health system environment that hosts the interventions. Solutions aimed at solving financial constraints simply by purchasing commodities for the front end of an intervention, without careful consideration for strengthening the delivery modes, will likely fail (51).

6.4 Implications for malaria vector control and personal protection

Although it is not explicit, it is clear that the first three elements of the GMCS cannot easily succeed in the absence of a functional health system. But in endemic countries where malaria is most severe, health systems are particularly weak. Therefore interventions, and particularly malaria interventions, need to be as simple as possible for the system to manage and deliver in order to retain as much of the original efficacy as possible.

Financial and human resources are always limited and inadequate for the health problems at hand. However, significant new financial resources are being mobilized for malaria, helping many countries to undertake for the first time nationwide malaria prevention and control programmes. The two most efficacious preventive interventions are IRS for vector control and ITNs for personal protection (and vector control at certain levels of coverage). This poses important strategic choices from a health systems perspective, given

the new health reform realities of decentralization, sector-wide approaches (SWAp) and integrated approaches.

6.4.1 Decentralization

One of the most tangible manifestations of current health reforms is decentralization of priority setting and resource allocation to district or local level health authorities. Where the health sector was formerly centrally planned, it is now increasingly locally planned. The centre provides policy guidelines and, in some cases, transfers of payment, while the local authorities must generate additional local funds and determine how staff will be deployed, how funds will be allocated, and how programmes will be implemented. In most cases this transition has moved at a pace faster than the skills, capacities, and management tool kits at local level have been able to cope.

Where interventions are logistically demanding, such as IRS, well supported vertical programmes can and do work well, even in low resource settings. An emerging problem in light of recent health reforms is that centrally managed vertical programmes are becoming less acceptable politically as central service ministries convert to policy ministries, and services decentralize to local government authorities with greater community control.

IRS is a very technically defined intervention with relatively high maintenance requirements that requires its own transport, logistics and supply chain, with strong supervisory oversight moving over large areas in tight time frames. Traditionally most vector-borne disease control has been managed as a vertical programme. The current move to devolution/decentralization is a considerable potential threat to the performance of IRS, an intervention that needs to achieve seasonally high coverage levels on schedule in order to have any effectiveness. Decentralization, the most common feature of health reforms, thus poses worrying challenges and potential opportunities for malaria vector control and personal protection.

6.4.2 Sector-wide approach

Most health resources in the poorest countries are needed for salaries and essential medicines, leaving little room to manoeuvre in terms of setting local priorities, embracing new interventions, or scaling-up. Additional resources for such initiatives were traditionally found in project funding which led to priorities being set by project donors. This also resulted in a patchwork of activities since projects tended to operate outside national and district health plans. The current solution for this is the SWAp approach where a partnership between the Ministry of Health and health sector donors

agrees that off-budget funding ceases, and donor funds are added directly into the sector. The central government and the donors jointly determine longer-term expenditure frameworks and annual budgets. Often a share of the SWAp funding is passed on to districts to support decentralization. This usually takes the form of a district health basket fund controlled not by the Ministry of Health but by a local authority under a Ministry of Local Government. Neither the donors nor the Ministry of Health earmark these funds for particular interventions or activities, but they may provide guidelines, set ceilings or minimums with regard to expenditure by type (e.g. ceilings for capitalization, allowances, etc.).

Again, the main questions under SWAp pertinent to malaria vector control and personal protection relate to power relations, decisions with regards to what gets funded and the concordance of local implementation with national guidelines and policies. Donors who may traditionally fund national malaria control programmes or specific malaria control activities in the pre-SWAp era now find that they need to trust the process that such investments will continue, and thus play only an advocacy role in the partnership with government. However, as donors move increasingly to sector and budget support, their need to maintain specialized staff in the sector becomes less, and this voice can disappear.

Many countries have included ITNs as a central component in their national malaria control programme and their national package of essential health interventions. This means that ITNs are generally “on the menu” to be selected by district planners. Districts that choose to invest in ITNs may simply invest in promotion and awareness programmes, or may go further and invest in purchasing social marketing services, or directly procure and distribute ITNs or net retreatment through public health facilities, as free or subsidized items. District health basket funding provides ample resources to initiate any of these activities, but scaling-up, especially for free ITNs or full-value vouchers, is beyond the resources of the current SWAp baskets. In such circumstances donor funding is needed.

6.4.3 Debt relief and poverty reduction strategy papers

Malaria is often a prominent feature of the most heavily indebted poor countries (HIPC). According to country poverty reduction strategy papers that underpin the debt relief, this should provide significant local currency that then needs to be channelled as additional resources to the social sectors including education and health. This should increase the budgets for these sectors dramatically and open opportunities for scaling-up. However, Ministries of Health have been generally weak in establishing and maintaining

official connections, so they may not be benefiting optimally. In some cases, concessional grants earmarked for malaria control have gone unrequested and unspent because the malaria control programme or the Ministry of Health was unaware of their existence.

6.4.4 Integration

A health system lesson that is emerging in recent years is the importance of integration of interventions. At the front lines where most health services are delivered, health workers need to be polyvalent and there is little room for specialists. This means that the more interventions are integrated, the more likely they are to be selected and delivered well. The Expanded Programme on Immunization (EPI) works by integrating across several diseases with a common entry point and delivery mechanism. This has helped EPI to survive relatively intact the transition from a vertical programme to a horizontal one. The Integrated Management of Childhood Illness (IMCI) is another example of an intervention that is popular at primary care levels because, through integration, it simplifies training, management, logistics, supply and supervision for case management for a broad array of major health problems, including malaria.

ITNs are a relatively new intervention for the health sector and lend themselves to a variety of delivery mechanisms, some of which can be provided by the private sector. Given the fragility of health systems in the poorest countries, and the difficulty of community outreach from such systems, there is a risk of overloading the public system (unless a vertical approach runs beside the system). If a district health system has to manage procurement, transport, warehousing, security, and inventory control before it can even consider targeting and providing ITNs to the public, this will place a major stress on the system resulting in inefficiencies and loss of effectiveness, not just for the malaria interventions, but others as well. If the model involves social marketing and some form of cost-recovery at any level, then there is the added complexity of handling and accounting for cash in a system that is not designed for this. All of these elements are routine in the private sector, and ITNs would therefore seem to be an ideal intervention for which one should consider some sort of public-private alliance.

6.4.5 Public-private alliances and contracting out

Despite the growing phenomenon of decentralization, there is still an important role for national efforts. This is particularly so in areas where economies

of scale need to be made, such as bulk procurement of commodities (nets, insecticide, etc.), and mass media approaches to demand creation and IEC.

For ITNs, procurement and demand creation have often been facilitated by national or international organizations that specialize in social or commercial marketing. However, on this scale, large tenders and contracts are usually involved. The current state of health reforms poses two problems here:

1. First, fiscal reforms have not kept up and many Ministries of Health may not have sufficient authority to let tenders above a certain trivial amount which is wholly inadequate for national scale enterprises. Cumbersome national tender boards under Ministries of Finance or other authorities then handle these, leaving the various stakeholders highly frustrated.
2. Secondly, under the SWAp approach, donors who would like to invest in such efforts, find that they cannot earmark their funds in this way, and are thus forced to work off-budget, take the risk with the SWAp, or abandon the idea.

For both IRS and ITNs, there is an important role of the health system in support of public-private alliances to help manage the issue of taxes and tariffs on insecticide, nets, and equipment required for the public good aspect of these interventions. In the health reforms, the new Ministries of Health will need to be much more involved in policy development, technical advice, regulatory issues, legislation, and consumer protection. In many instances this will require new skills and human resources with specific expertise in policy analysis, law, economics, and business administration.

6.4.6 Capacity strengthening

Capacity strengthening is needed at all levels of a vector control programme and in selecting vector control strategies. The implementing process will identify key personnel to carry out activities and training needs will become obvious.

WHO provided comprehensive guidance on the particular role of vector control in two reports from WHO Study Groups that met in 1993. In its report, the *WHO Study Group on the Implementation of the Global Plan of Action for Malaria Control* (52) gave thorough attention to the topic of programme management including the importance of management for preventive services. In its companion report, the *WHO Study Group on Vector Control for Malaria and Other Mosquito Borne Diseases* (53) took up the topic of programme management and devoted special attention to the needs for capacity building, recognizing that 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. Note is taken of these reports because most of their findings and recommendations remain valid today. If anything, the current status of entomological expertise and vector control capabilities is more challenging today in many countries than it was ten years ago. This is because vector control functions have not adjusted to important changes over this period.

Particularly important is the decentralization of health services, which has progressed markedly and even rapidly in some countries. As district-level officials have gained more authority for setting priorities and allocating health sector resources, vector control functions have declined. This is because such functions have historically been focused at the central level and vector control programme managers almost only at the central level. Where they exist at the district level, they have not been effective in advocating for resources under the new management schemes.

It is nevertheless encouraging that, while this decline of entomological expertise and vector control services was occurring in many countries over the past ten years, health authorities are becoming aware of the need to reverse this trend. A first step in any national malaria vector control capacity strengthening is to undertake a comprehensive assessment of national vector control needs. The process of addressing the capacity strengthening needs for planning and implementation identified in the vector control needs assessment may include issues at the district level.

7. Conclusions and recommendations

7.1 On appropriate strategies and operational issues in eco-epidemiological settings

IRS and ITNs can be considered measures of almost general applicability, while other measures may be applicable in particular circumstances. The process of deciding about which mosquito control method is appropriate in a given situation should be guided by an analysis of the level of malaria endemicity and vector bionomics, the eco-epidemiological setting, the health management system and an estimate of the programme sustain-

ability. The following recommendations should be taken into consideration in such selection:

- a. IRS should only be adopted if the necessary infrastructure exists or can be created to achieve and sustain high coverage and where local vectors are susceptible to the insecticides used.
- b. An ITN programme should aim for high coverage and use and should ensure that all mosquito nets are treated with insecticide, either through regular free re-treatment or distribution of LLINs. Follow-up should be carried out to ensure continuous availability as well as regular and appropriate use of ITNs.
- c. For larval control to be effective one must find and effectively treat a very high proportion of the breeding sites located within the vector flight range of the community to be protected.
- d. Contracts for development projects should include binding guidelines for design and operational safeguards aimed at preventing creation of man-made vector breeding sites or ensuring proper vector management in those sites.
- e. Monitoring and evaluation should include assessment of epidemiological indices (disease prevalence in different ecological set-ups or ecotypes) and, where feasible, assessment of entomological indices (vector density and vectorial capacity).
- f. Monitoring of vector resistance should be part of every malaria vector control programme using insecticides (adulticides or larvicides).
- g. Insecticide resistance management tactics should be implemented in any sustained vector control programme relying on the use of insecticides.
- h. When an epidemic occurs a rapid assessment must be made as to whether vector control may have an impact on disease transmission. If this is the case, vector control measures must be implemented promptly.
- i. Considering the magnitude of disease transmission, there is a need to combine vector control interventions in the context of integrated vector management. In specific circumstances larviciding, eventually associated with environmental management, might be a useful complement to IRS or ITNs.
- j. Knowledge of both vector ecology and behaviour will determine the choice of intervention to be used. This will include chemical control (use of adulticides and/or larvicides), a combination of methods (e.g. ITNs and IRS; ITNs and larviciding), mechanical control (house screening) and/or source reduction (e.g. drainage).

- k. To ensure consistency of effort and avoid work duplication, there is need to initiate an intersectoral collaboration as well as involve communities in the implementation of integrated vector management activities.

7.2 On health systems

The unrelenting development of antimalarial and insecticide resistance as well as the increasing costs of alternative control measures require continuous effort to make optimal use of available control tools by improving access, targeting provider compliance and consumer adherence. Moreover, all existing health systems are in a process of reform to which the strategy of malaria vector control has to adapt, both at the policy as well as the implementation levels. This adaptation should consider the following recommendations:

1. A share of funding from the Global Fund against AIDS, TB and Malaria, and other new initiatives should be devoted to general strengthening of health systems, including health management information systems. This would include human resource development and capital support in addition to the recurrent support for commodities provided by such initiatives.
2. Debt relief and SWApS provide an under-exploited opportunity to increase support for scaling-up malaria interventions through strengthening health systems and direct support. Ministries of Health should take a more proactive stance in accessing these resources. The degree to which debt relief and SWAp funding is channelled to malaria control should be an indicator that is reported in the annual *Global Malaria Report*.
3. Integration of vector control and personal protection into the health system through innovative linkages to ongoing health programmes and campaigns will probably lead to strong synergies, economies, and more rapid scaling-up compared to new vertical programmes.
4. Increased attention to public-private alliances is needed for efficient full-scale implementation of malaria control interventions, including vector control and personal protection.
5. Active community involvement should be encouraged, as it is essential for effective personal protection and vector control interventions.
6. Malaria control programmes should have comprehensive strategies for human resource development, including qualification in vector control and participation in operational research, career and training opportunities. Training may include:

- i.* For staff with managerial responsibilities: access to training courses, and tools for vector control personnel in managerial process and planning, basic transmission dynamics, epidemiology, entomological investigations, budgeting/finance/procurement, communications, and human resource management. Post-training opportunities for utilization of acquired skills should be provided.
- ii.* For staff with operational responsibilities: training for implementation of programme activities, e.g. spraying techniques, treating mosquito nets; household survey, KAP studies, IEC and advocacy should be amongst their programme's priorities.

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Annex

Endorsed outline of strategic framework for strengthening implementation of malaria vector control and personal protection

Choosing appropriate vector control/personal protection strategies.

1. ASSUMPTIONS

- 1.1 Framework is for countries where malaria prevention is part of national malaria control strategy and which face a choice of vector control methods.
- 1.2 Framework is predicated on the view that a competent health system is a necessary vehicle for achieving effective coverage of interventions.

2. STEPS

2.1 At policy level (lowest level at which policy is set; depends on appropriate national administrative institution for technical input)

2.1.1 Determine the eco-epidemiologic and health system setting (using the WHO TRS as a guide) by:

- a. determining and endorsing interventions to be included in the official national package of approved health interventions;
- b. establishing minimum standard operating procedures for each intervention:
 - i. links to WHO Technical resources/strategic frameworks;
 - ii. local standard operating procedures prepared by the appropriate national administrative institution.
- c. packaging each intervention's planning requirements for easy adoption by decentralized implementers.

2.1.2 Enhance the health system support environment to increase coverage and scale-up by:

- a. developing strategies for capacity building and human resource development;
- b. addressing regulatory and legislative issues;

- c. understanding National Health Accounts and Expenditure Frameworks;
- d. mobilizing and advocating for financial resources (central revenue, SWAp, HIPC, MTEF, basket funds, GFATM, Private/NGOs, etc.);
- e. mobilizing capital support for infrastructure and procurement;
- f. providing bulk procurement support for commodities required;
- g. ensuring quality of commodities procured;
- h. managing broad partnerships in support of malaria control, including private sector alliances where advantageous.

2.1.3 Articulate and advocate for an implementation research agenda that serves the needs of the implementation level.

2.2 At implementation level (decentralized, i.e. lowest level at which intervention resource allocation decisions are made; depends on policy level and technical support resources for input)

2.2.1 Choosing intervention(s):

- a. conduct local situation analysis (if necessary) to confirm local eco-epidemiologic stratification and health system settings in the decentralized jurisdiction, and determine the current performance of the system (RBM situation analysis tool, HealthMapper, system analysis, coverage, etc.);
- b. determine relative priority of competing intervention options at the local level (using planning guidelines and tools);
- c. choose appropriate intervention(s) from the national list, appropriate for the setting(s);
- d. conduct microplanning of selected intervention(s) including budget and resource requirements (using local planning guidelines and tools):
 - i.* involve all relevant stakeholders, technical advice and community input;
 - ii.* look for integration synergies within the system;
 - iii.* make realistic timelines and resource scheduling;
 - iv.* establish minimum performance and process indicators;
 - v.* build in plans and budget for monitoring and supervision.
- e. determine central resources and mobilize additional local resources;
- f. allocate resources;
- g. drive and monitor the implementation of the intervention(s).

Malaria transmission rates and risks can be greatly reduced by vector control, mitigating high malaria incidence and prevalence rates. Methods and strategies for malaria vector control (MVC) have been well documented by WHO, although its implementation varies widely. Technical guidelines for MVC strategies and materials are readily available, but the status and role of MVC have not been reviewed and redefined in terms of programme management and resource allocation. There are huge changes since November 1993 when the last WHO Study Group reviewed vector control for malaria and other mosquito-borne diseases, following the 1992 adoption of the Global Malaria Control Strategy.

Operationally, with reform of the health sector in many countries, the centrally managed and vertically structured malaria control programme (MCP) has been superseded by a community-based and decentralized one. This poses challenges for effective implementation of MVC strategies. Therefore it became evident that the role of vector control in malaria control needs to be reconsidered to develop a strategic framework for MVC implementation by national malaria control programmes and other partners.

This report of a WHO Study Group on Malaria Vector Control and Personal Protection reviewed the current vector control strategies and their effectiveness in various operational and eco-epidemiological settings, and identified challenges for implementation in different health systems. An outline strategic framework for strengthening malaria vector control implementation was developed. The process of deciding about which mosquito control method is appropriate in a given situation should be guided by an analysis of the level of malaria endemicity and vector bionomics, the eco-epidemiological setting, the health management system and an estimate of the programme sustainability. This report also provides a basis for the development of a strategic framework for strengthening malaria vector control implementation.

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