Amazon Malaria Initiative/ Amazon Network for the Surveillance of Antimalarial Drug Resistance

Strategic Orientation Document for Malaria Vector Surveillance and Control in Latin America and the Caribbean

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Amazon Malaria Initiative/ Amazon Network for the Surveillance of Antimalarial Drug Resistance

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Glossary

Anthropophagic: when vectors feed preferentially on humans

Entomological inoculation rate (EIR): the number of bites from an infectious mosquito experienced by an individual per unit of time

Endophagic: when vectors preferentially feed indoors

Endophilic: when vectors preferentially rest indoors

Exophagic: when vectors preferentially feed outdoors

Exophilic: when vectors preferentially rest outdoors

Gonotrophic cycle: the egg production cycle in female mosquitoes, which includes blood meal digestion, egg maturation, and oviposition

Monitoring: systematic tracking of program actions over time

Primary vector: an arthropod that transmits a pathogen or parasite from one vertebrate host to another and that is able to sustain the organism in its natural cycle

Secondary vector: an arthropod that transmits a pathogen or parasite from one vertebrate host to another but that cannot sustain the organism in a natural cycle without transmission by a primary vector

Species complex: a group of species that is reproductively isolated from each other but with very similar morphology

Surveillance: the ongoing systematic collection, analysis, and interpretation of data and the dissemination of data to those who need to know in order for action to be taken

Synergists: inhibitors of detoxification enzymes, such as esterases, oxidases and glutathione S-transferases, that are important in the metabolism of insecticides

Sympatric: populations with an overlapping distribution or that coexist

2 ACRONYMS AND ABBREVIATIONS

AMI	Amazon Malaria Initiative
API	Annual parasite index
CDC	U.S. Centers for Disease Control and Prevention
DDT	Dichlorodiphenyltrichloroethane
HBI	Human blood index
HLC	Human landing catches
IRS	Indoor residual spraying
ITNs	Insecticide-treated nets
IVCC	Innovative Vector Control Consortium
IVM	Integrated vector management
LLINs	Long-lasting insecticide-treated nets
NMCP	National Malaria Control Program
PAHO	Pan American Health Organization
PSC	Pyrethrum spray catches
RBM	Roll Back Malaria Partnership
SR	Source reduction
USAID	United States Agency for International Development
WHO	World Health Organization
WHOPES	WHO Pesticide Evaluation Scheme

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Objective

The purpose of this document is to serve as a strategic guide to address malaria vector surveillance and control in the Americas, where malaria transmission is characterized as moderate to low. This document summarizes the discussions and recommendations of the Amazon Malaria Initiative (AMI) technical advisory group and aims to promote strategies that are evidence-based. It is intended that this document will be updated regularly to incorporate new developments, findings, input, and suggestions from partners, as well as those arising from its own implementation.

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Introduction

Since documenting the interruption of malaria transmission in several countries in the 1960s, 23 countries in the Americas still have endemic malaria transmission: Argentina, Bahamas, Belize, Bolivia, Brazil, Colombia, Costa Rica, Ecuador, El Salvador, Guatemala, Guyana, French Guiana, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, Dominican Republic, Suriname and Venezuela (PAHO 2010).

The region reported 524,123 laboratory-confirmed malaria cases in 2009 (representing a 56% reduction in malaria morbidity in the region as compared with 2000) and 109 deaths in 2009 (a 70% decrease relative to the 2000 baseline figures). Seventy-four percent of infections were caused by *Plasmodium vivax*, 26% by *Plasmodium falciparum*, and less than 0.1% by *Plasmodium malariae* (locally reported in Brazil, French Guiana, Guyana, Suriname, and Venezuela) (PAHO 2010). Recent trends suggest that some countries, such as Argentina, El Salvador, Mexico, and Paraguay, will likely continue to advance toward elimination of the disease in coming years.

The transmission dynamics of malaria in the Americas comprises a complex epidemiological scenario: both *P. falciparum* and *P. vivax* parasites are sympatric in the human host and in the vector population. There is wide diversity of anopheline species that are competent vectors that coexist with a temporal succession favoring sustained transmission. As a result, patterns and intensity of malaria transmission can be remarkably diverse, requiring a variety of approaches for entomological surveillance and vector control.

Entomological surveillance is a cornerstone of effective and sustained malaria control. However, the best developed malaria vector surveillance indicators and techniques are mainly applicable to areas with high malaria transmission and, in the Americas transmission levels very seldom fall within this category. Malaria endemic areas of the Americas are generally considered moderate to low transmission settings. The inadequacy of traditional entomological surveillance strategies in these transmission settings has become evident as efforts to implement them have been met with considerable challenges.

Malaria vector control programs rely on the indoor residual spraying (IRS) of insecticides and the distribution of insecticide-treated bed nets (ITNs) as primary vector control tools. However, there are significant knowledge gaps regarding their efficacy in the Americas, where different vector species vary substantially in host-seeking behaviors and respond differently to interventions. Thus, it is anticipated that a scale-up of these interventions might produce varying degrees of success, depending on local entomological and epidemiological contexts. Therefore, the use of regionally relevant entomological indicators to monitor impact will allow for vector control programs to monitor the effectiveness of these strategies and, where necessary, to seek alternatives.

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Vector control

Interventions targeting malaria vectors are one of the most effective ways to prevent and reduce malaria transmission and are key technical elements of the World Health Organization's (WHO) Global Strategy for Malaria Control (WHO 1993). At present, vector control is one of the most important malaria control tools available, and may lower transmission to levels where elimination can be envisioned.

Vector control through the application of residual insecticides was once the mainstay of malaria control in the Americas, and considerable reductions in malaria cases and elimination of the disease in some regions was achieved. Factors that affected the efficacy of IRS included insecticide resistance, exophily, exophagy, behavioral avoidance, economic constraints, and public concerns about environmental contamination. The conclusion of the Global Malaria Eradication Program (GMEP) and the subsequent implementation of global policies and strategies for malaria control that promote the reliance on case treatment contributed to a de-emphasis on vector-based strategies (WHO, 1979, 1985, 1992). During this period, vector control activities in the Americas become reactionary, with poorly coordinated control efforts in response to increases in malaria cases.

When properly implemented, ITNs and IRS are the two malaria vector control strategies with the most proven efficacy that are currently available. These two strategies can significantly reduce the malaria burden by reducing the vector population, reducing the life of adult female mosquitoes, and preventing vector contact with humans. Larval source reduction (SR) remains as a supplemental strategy, since it can only impact disease by reducing vector abundance. Due to its high cost and low long-term effectiveness for malaria control, space spraying is used to reduce vector densities over the short term, usually only in emergency situations.

Successful malaria control and elimination in the Americas requires effective control of the *Anopheles* species that serve as malaria vectors. Several factors limit the effectiveness of vector control in this region, including: (1) the lack of knowledge of the composition of the vector system in many settings and how anthropogenic alterations of the environment influence transmission dynamics; (2) a limited number of vector control strategies and a lack of information on how vectors present in this region adapt to overcoming the effects of these strategies; and (3) the lack of evidence-based field research and rigorous evaluation of strategies to guide the effective implementation of integrated vector management (IVM).

The major malaria vectors in the Americas have a wide-scale distribution in diverse environments and show a high variability in their behavioral patterns even within populations of the same species. To date, 18 *Anopheles* species have been listed as important malaria vectors in the Americas, of which five are considered primary vectors. In addition to primary vectors, low levels of transmission are frequently maintained by a number of behaviorally and ecologically diverse secondary vectors. Annex 1 lists all primary and secondary vectors currently recognized in the Americas.

The selection of appropriate vector control tools should take into account the heterogeneity of the vector populations' behavior and environment. Given that a variety of anophelines can become infected with *Plasmodium spp.*, an assessment of epidemiological potential in different settings and/or transmission foci is required to determine which interventions are likely to deliver the greatest impact.

Vector control should be targeted to high malaria risk areas, and IRS and ITNs should be considered measures of general applicability. The process of deciding which of these two vector control strategies to implement in a given situation should be guided by an analysis of the level of malaria endemicity, vector bionomics, eco-epidemiological characteristics, operational feasibility, community acceptance, and program sustainability. Depending on the specific malaria transmission dynamics and endemicity of malaria in an area, some interventions may not be cost-effective, so vector control programs should first consider these factors before deciding which interventions to apply.

Achieving high coverage is of crucial importance to reaching maximum impact on malaria transmission within a given vector control strategy. The Roll Back Malaria Partnership (RBM) recommends at least 80% coverage of a malaria control intervention in order to achieve considerable impact on malaria transmission. Following this guidance, malaria control programs should aim to reach high levels of coverage if they are to truly have an impact on transmission.

5.1 Indoor residual spraying

Vector reduction through the indoor application of residual insecticides was once the mainstay of malaria control in the Americas. When IRS was extensively used in Latin America during the malaria eradication campaign of the mid 1900s, no quantification of its impact on malaria cases and entomological parameters was recorded (Pluess *et al.* 2010; Tanser *et al.* 2010). However, historical and program documentation has clearly established the impact of IRS on malaria control and has credited it with eliminating malaria from several parts of the world, including the United States. IRS reduces the human biting rate by both killing mosquitoes and repelling them through an irritant effect. Since IRS targets endophagic and endophilic vectors, its effectiveness may be not optimal in areas with vectors that have different feeding and resting behaviors.

According to the latest WHO report (WHO 2010), of the 23 countries and territories with endemic malaria transmission in the Americas, 14 recommend including IRS for malaria control. In 2009 eight countries used IRS for the prevention and control of epidemics and 10 countries used it in combination with ITNs. Targeted, focalized IRS has been used in at least three countries for malaria control. In 2009, an estimated 7,888,251 people at risk of malaria were protected by the use of IRS (WHO 2010).

From the 20 classes of chemicals registered for use in controlling agricultural or domestic pests, only four classes have been registered for public health use against arthropod disease vectors. Currently, 12 insecticides within these four classes are recommended by WHO for use in IRS. Information on the insecticides approved for public health use can be found on WHO websites such as: http://www.who.int/whopes and http://www.who.int/malaria/vector_control/irs/en/index.html. Annex 2 lists the insecticides currently recommended by WHO for IRS.

5.2 Insecticide-treated nets

The use of ITNs, including long-lasting insecticide-treated nets (LLINs), has shown substantial impact on malaria transmission, clinical disease, and childhood mortality in Africa. ITNs protect individuals either by killing mosquitoes that attempt to feed on persons protected by a net or by diverting host-seeking mosquitoes to search for a blood meal elsewhere. ITNs can also exert a community-wide effect, reducing mosquito density, survival, human blood indices, and feeding frequency over large areas where ITNs are in use (Gimnig *et al.* 2003).

During the last decade, through the aid of international donors, the distribution of LLINs has risen steadily and constitutes today the main activity for malaria vector control in the Americas. More than three million LLINs have been distributed throughout the South American continent to date and a rapid scale-up of ITN distribution is expected in the near future. According to the 2010 WHO Malaria Report, 15 of the 23 malaria-endemic countries in the Americas reported having a policy of providing ITNs in 2009. ITNs were distributed to all age groups in 13 countries, and two countries have undertaken mass campaigns targeting households with children under five years of age. Five countries reported the distribution of ITNs through prenatal clinics. ITNs were mainly distributed free of charge in 12 countries, and were otherwise sold at a subsidized price.

ITNs have been tested extensively on the African *P. falciparum* transmission cycle, but the information available regarding ITN efficacy in other epidemiological contexts is limited. There is little understanding of the scale of how this intervention might impact malaria transmission in other parts of the world. ITNs are particularly suitable for mosquitoes that bite nocturnally and both bite and rest indoors. It is generally perceived that ITNs are less effective against exophilic and exophagic mosquitoes like *Anopheles darlingi*, the principal vector of malaria in the Amazon. Due to the lack of information on the dynamics of local vectors and their response to ITNs, it is difficult to predict outcomes for when ITN distributions are scaled-up. Therefore, it is important to monitor changes in mosquito populations and behavior as part of ITN distribution programs.

Under current guidelines and practices, LLINs are defined as maintaining adequate insecticidal activity after 20 standard washes or a minimum of three years under routine use in the field. The WHO Pesticide Evaluation Scheme (WHOPES) has given an interim recommendation to six net products that have met the first part of the criteria but have not had adequate time for field-testing. Two net products have met both criteria and have been given full recommendation by WHOPES. The insecticides used in all recommended LLINs and in most conventionally treated nets belong to the pyrethroid family of insecticides, which are considered particularly safe for human use due to their low mammalian toxicity. Countries considering the use of ITNs as a malaria control strategy should ensure that either conventionally treated nets are regularly retreated with insecticides or that adequate distributions of LLINs are in place, including upkeep and replacement strategies. Annex 3 shows the WHO-recommended LLINs to date. Further details can be found at http://www.who.int/whopes.

5.3 Source reduction

Source reduction (SR) is the temporary or permanent elimination of anopheline larval habitats, often by using chemical or biological larvicides. In terms of impacting the vector population and reducing malaria transmission, SR only reduces vector abundance. Reducing vector abundance has a comparatively lower impact on malaria transmission than strategies that reduce vector-human contact.

SR approaches may be feasible in areas where larval habitats are few, accessible, and can be clearly defined. For this approach to be effective, a high proportion of the breeding sites within the vector flight range must be treated. Thus, SR is usually only recommended in very specific situations, such as when outbreaks occur and in certain urban settings.

Some programs that have employed SR within their malaria vector control strategies have used environmental management as well as the application of larvicides. The outcome of these efforts has been mainly a reduction in mosquito densities, with no documented impact on reduction of malaria cases (PAHO 2006, 2010; Walker & Lynch 2007).

SR has limited applicability in the Americas due to the inaccessibility and wide range of breeding sites of the main malaria vectors in the region. Thus, SR using larvicides is not currently recommended as a tool for malaria control on its own. It remains as a potential strategy, and recent studies conducted in Africa indicate that SR targeting human-made breeding sites may significantly reduce malaria in appropriate settings. In addition, SR may have a role as part of an integrated vector management (IVM) program, since it has been documented that SR can amplify the impact of ITNs and IRS (Walker & Lynch, 2007).

5.4 Integrated vector management

IVM has been defined as a "rational decision-making process for the optimal use of resources for vector control" (WHO 2007) and includes five key elements: 1) an evidence-based decision-making process; 2) the use of integrated approaches; 3) collaboration within the health sector and with other sectors; 4) support through advocacy, social mobilization, and legislation; and 5) capacity building.

The use of two or more vector control methods in the context of IVM is believed to be an effective strategy when each method targets different points in the transmission cycle. There is a consensus in the region of the Americas that malaria control, and eventually elimination, is far more likely if the best available tools are used in combination.

IVM has been slowly introduced for malaria control in the Americas (Feachem *et al.*, 2009; PAHO, 2006). Some programs have incorporated IVM elements but, in general, it has been insufficiently applied and evaluated in the region. However, when IVM strategies have been comprehensively implemented in African countries, they have successfully controlled malaria transmission (Beier *et al.*, 2008).

Although IRS and ITNs are effective individually and can achieve dramatic decreases in malaria prevalence, few studies have explored the synergistic effect of the combined use of IRS and ITNs. The rationale behind this approach is that transmission should decline more rapidly due to greater insecticide coverage and that the development of insecticide resistance can be delayed if different classes of insecticides are used for IRS and ITNs. Evidence resulting from this combined approach shows results varying in effect, with some studies showing a greater impact as a result of the combination, and others showing no benefit when compared with either IRS or ITNs alone (Yakob *et al.* 2010).

The current evidence is insufficient to properly quantify the additive effect of SR, or the impact of combining ITNs, IRS, and SR in malaria transmission reduction; nor is there sufficient evidence to predict the most cost-effective combination of vector control strategies. Developing a body of evidence from trials conducted through the coordinated efforts of research groups and vector control programs is necessary to address this significant gap in operational knowledge.

6

Vector surveillance

Surveillance and monitoring are integral parts of vector control and are essential prerequisites to the rational design, implementation, and evaluation of vector control programs. Surveillance provides ongoing information about the impacts that interventions have on the vector population. Monitoring of control activities provides feedback about implementation to identify problems or constraints. Both surveillance and monitoring are necessary to evaluate the efficacy and effectiveness of vector control interventions. Evaluation can provide key information on the successes and challenges of intervention strategies, and thus guide the planning of subsequent control activities.

Vector surveillance, monitoring, and evaluation should be contextualized within regional and national malaria control programs, taking advantage of the possible collaborations with other government health programs or research institutions working in this area. Central or regional reference entomology laboratories, where available, can often provide technical assistance with these activities.

An enhanced vector surveillance system tailored to moderate to low-transmission settings, which can be employed easily and routinely within a public health surveillance context, is proposed in this guidance document. The monitoring plan focuses on a limited number of indicators, which can be gathered at a reasonable cost and are operationally relevant.

The indicators selected for this document include indicators of entomological impact or risk of exposure and indicators related to the operational implementation of control strategies (ITNs and IRS). When data are systematically gathered, these indicators can provide information on where and why an intervention is or is not producing the expected epidemiological impact. Effective vector control also requires trained personnel, supervision of control operations, and periodic evaluation of the impact of the control measures on the targeted vectors and on disease incidence or prevalence.

6.1 Entomological surveillance

Goal and objectives

Entomological surveillance is an integral part of vector control and should be tailored to the types of control strategies being used and program capabilities. The goal of entomological surveillance is to monitor some of the critical vector characteristics that will guide the planning, implementation, and evaluation of malaria vector control programs.

Entomological surveillance aims to:

- Identify the vector population that will be targeted by control measures;
- Guide the optimal timing for the implementation of vector control strategies;
- Detect behavior patterns in vectors that could limit the efficacy of vector control interventions;
- Monitor the entomological impact of vector control interventions;
- Detect the development of insecticide resistance and the modes of resistance.

Overview of the vector surveillance system

A universally applicable malaria vector surveillance system does not exist, thus local entomological surveillance should be tailored according to the level of malaria risk and the resources available for surveillance. Given the complexity of malaria transmission in the Americas, surveillance programs should be planned and designed using the best available knowledge regarding the ecology of local vector species and malaria transmission dynamics.

The proposed surveillance strategy serves as a tool to document the sustained efficacy of vector control measures and provides a basis for measuring their effectiveness. As programs successfully reduce malaria transmission, the measurement of entomological indicators become increasingly difficult and insensitive, particularly when determining vector infection rates. To compensate for changes in transmission, the surveillance strategy should be continually evaluated and updated.

Several models have attempted to explain and predict the relationships between vector indices and malaria transmission. Vector abundance, infection rate, and the life expectancy of infectious mosquitoes have been identified as key elements associated with malaria transmission. Entomological surveys should be carried out at regular intervals, and in areas of higher malaria transmission, entomological indicators need to be monitored more frequently because changes in morbidity and mortality may occur in a shorter period of time. As a general approach, in areas of high to moderate transmission, entomological surveys for vector presence and behavior should be done every month during the transmission season; in areas of moderate to low transmission, surveys should be done three or four times a year during the transmission season; in areas of low to very low transmission, surveys should be done two times a year during the transmission season; and finally, in areas with no transmission but at risk of transmission, monitoring should be done once a year. Once a general understanding of transmission dynamics is established, entomological surveillance programs can tailor the periodicity and intensity of their monitoring to particular settings and situations. Based on the reported incidence of malaria in the Americas, endemic areas may be classified into three main categories: moderate to low malaria transmission, low to very low malaria transmission, and no transmission but at risk of transmission.

Dependent upon program capabilities, it is recommended that baseline data be collected in an area before an intervention is implemented. This information can be used to monitor the impact of control measures and also help determine the frequency of future monitoring. If changes in transmission occur, the frequency of data collection may be increased to ensure adequate monitoring of the impact of remedial actions. Entomological data should be linked with ongoing epidemiological surveillance to evaluate disease transmission and the number of malaria cases.

Entomological survey sites

Surveillance that covers the entire area at risk is the best approach for understanding how vector control strategies are impacting the vector population. Such an approach is particularly challenging since it can be extremely difficult to sample mosquitoes over large areas. An alternative is to conduct surveillance at sentinel sites corresponding to areas of priority concern for entomological surveillance and vector control activities. It is assumed that the mosquito populations present at these sites are representative of larger geographical areas. This approach permits the collection of longitudinal data that, when linked to malaria incidence, can measure the sustained impact of vector control interventions. It also enables the optimal use of limited resources, making sentinel site-based surveillance a particularly attractive and recommended approach for the collection of entomological data in the Americas.

Sentinel sites should be representative of the greater area that is under surveillance. Sites should represent relevant eco-epidemiological zones and areas of ongoing vector control or areas where it is likely that vector control interventions will be used. To identify eco-epidemiological zones, regions should be delimited using determinants of malaria transmission intensity, such as (1) environmental elements (geology, vegetation, climate, rivers, etc), (2) geographical determinants (altitude, temperature, humidity, rainfall), (3) human presence and distribution of rural versus urban populations (roads, cities, land use, etc), and (4) main vector distributions. In general, malaria programs have a sense of these major eco-regions, and several existing publications on eco-regions can serve as starting point for individual countries to better define these regions (Rubio-Palis & Zimmerman 1997; WHO 2006).

The major epidemiological strata of malaria transmission were originally defined in the context of the WHO's Global Strategy for Malaria Control (WHO 1993), and subsequently adapted by Castillo-Salgado (1992) for specific for use in the Americas. The Pan American Health Organization (PAHO) proposed the use of a stratification process using annual parasite indexes (API). Areas of high to moderate transmission are those with API ≥1 per 1,000 habitants; areas of low transmission are those with API <1 per 1,000 habitants. These latter areas correspond to areas that could be considered for pre-elimination. This system also includes areas with no current malaria transmission but where transmission could potentially occur. Other Amazon Malaria Initiative (AMI)-supported documents, particularly *Estrategia para la toma de decisiones en control racional de vectores de malaria para los países de la región de las Américas,*[1] discuss additional approaches.

The number of sentinel sites chosen to monitor the selected indicators depends on the capacity of local staff, costs, and availability of resources. However, at least one sentinel site per eco-epidemiological zone should be established and long-term surveillance should be conducted. Sites should be located in areas of greatest malaria incidence and pesticide use (for both agricultural and public health purposes). The relevance of sentinel sites may vary over time. Thus information must be analyzed continuously to take into account any changes in vector behavior, alterations in patterns of disease transmission, environmental changes, and human population movements.

Entomological indicators

The objective of entomological surveillance is highly qualitative, i.e. to determine if anopheline vectors are present and to identify their composition, seasonality, and susceptibility to insecticides. It also aims to detect changes in patterns of human-vector contact and if vector behavior is modified as a result of control measures. Routine monitoring of these indicators is essential to ensure continued effectiveness as vector populations change in response to intervention pressures. As transmission intensity decreases, the measurement of some entomological indicators becomes increasingly difficult and less sensitive, particularly those related to mosquito infection rates. Therefore, this guidance

1. Strategy for rational decision-making in control of malaria vectors for the countries of the region of the Americas. Available in Spanish at www.paho.org/spanish/ad/dpc/cd/ravreda-guia-control-vectores.doc

document lists two sets of entomological indicators. The first set is listed in Table 1 and represents basic entomological indicators. The second set of entomological indicators is listed in Table 2 and is applicable to special settings and circumstances when in-depth surveillance is required and financial resources are available.

In summary, monitoring vector species populations is a systematic activity that should be conducted at regular intervals depending on the transmission level. Indicators should be monitored at regular intervals during the transmission season according to transmission levels and at the same sentinel sites over long periods of time.

Table 1. **Basic entomological indicators to consider as part of malaria vector control programs in the Americas.**

Indicator	Definition
Presence of malaria vectors and species composition	Detection of the vector species present in a given area.
Spatial and seasonal distribution of vectors	Number of vector species present per unit of surveillance and time.
Relative abundance	Number of vectors of a given species per unit of collection and time.
Feeding behavior	Number of mosquitoes attempting to bite inside/outside the house per unit of collection and time.
Insecticide susceptibility	Ability of a given dose of insecticide to kill the vector population.

Table 2. **Intermediate entomological indicators to consider in special circumstances as part of malaria vector control programs in the Americas.**

Indicator	Definition
Human blood index	Proportion of vectors with human blood meals per unit of time
Malaria infection rate	Proportion of mosquitoes with malaria sporozoites
Parous rate	Proportion of female anophelines that have oviposited at least once.

Surveillance methods

Entomological surveillance involves collecting mosquitoes for different types of analyses. The selection of the trapping method should be based both on the behavior of the species and on the indicator that is being investigated.

The entomological indicators described here rely on the collection of *Anopheles* mosquitoes. Human landing catches (HLC) remain one of the most effective and informative collection methods for the species most common in the Americas. HLC allows for the collection of data on key mosquito behaviors, such as host seeking and feeding. Alternatives to HLC that have been field-tested in the Americas include the U.S. Centers for Disease Control and Prevention (CDC) light traps, CO_2

baited traps, human baited traps, pyrethrum spray catches, aspirator collections of indoor-resting mosquitoes, and outdoor resting collections. However, previous studies have consistently shown that the majority of anophelines in the Americas are not readily caught in traps, limiting their use in the region. Pyrethrum spray catches (PSC) are not recommended due to low levels of exophily in the local anophelines. Entry/exit window traps have not been widely used in the region, but the data generated to date show that considerable numbers of *Anopheles albimanus, An. darlingi,* and *An. vestitipennis* can be caught either entering or exiting houses. Their potential as a surveillance tool in the Americas needs to be further evaluated with different vectors and in different settings.

6.2 Monitoring vector control operations

Goals and objectives

IRS campaigns and the distribution of ITN s must be carried out with skill and achieve high coverage to be effective. A reliable monitoring strategy can ensure the accurate collection of this operational information. Table 3 lists operational indicators that should be monitored regularly when using ITNs and IRS.

The monitoring of operational indicators can be achieved through a variety of methods. ITN distribution campaigns and routine distributions should be closely monitored. Statistically robust coverage surveys should be conducted at regular intervals to evaluate ITN ownership and use (details on the suggested regularity of these can be found in the specific malaria transmission level section of this document). In addition, surveys should be conducted to assess how different cultural practices and ITN care habits can influence ITN physical durability and insecticide retention.

IRS operations should be monitored closely by the implementation agent. The quality of IRS applications should be evaluated to assess the efficacy of the spraying through the use of standard methods such as the WHO cone bioassay. Monitoring may include an evaluation of IRS coverage by an agent independent of the implementer. Standardized methods, strategies and guidelines to monitor the appropriate ratio of insecticide per surface area are still under development by technical partners including the CDC and the Innovative Vector Control Consortium (IVCC). As with ITNs, operational research activities and evaluations should be conducted to evaluate the long-term effect of the spraying.

Many countries routinely conduct major demographic and health surveys that include the collection of data on indicators that are relevant to malaria control. National Malaria Control Programs (NMCPs) should consider reviewing those surveys and coordinating efforts to ensure that malaria indicators are included in such surveys. Doing so could help decrease the costs associated with the monitoring and evaluation of activities specifically for malaria.

Table 3. **Operational indicators to consider for use in the Americas to monitor vector control programs using ITNs and IRS.**

Vector control strategy	Indicator	Definition
ITN	Household coverage of ITNs	Proportion of households possessing ≥1 ITNs out of those targeted.
	Sufficient household coverage of ITNs	Proportion of households where the number of ITNs is ≥ number of beds/sleeping spaces, among those targeted.
	ITN usage	Proportion of people reported sleeping under an ITN the previous night out of those targeted.
	ITN survivorship	Proportion of nets distributed in a campaign that are still present in target households.
	ITN insecticidal activity	Proportion of ITNs with adequate levels of insecticidal activity among those surveyed.
	Physical integrity	Proportion of ITNs that are still in acceptable physical condition among those surveyed.
IRS	IRS coverage	Proportion of houses/structures sprayed among those targeted.
	Insecticidal effect on sprayed surfaces	Mosquito mortality per cone bioassay on sprayed surfaces at regular time intervals after IRS application.
	Dosage of insecticide*	Ratio of the quantity of insecticide present to the wall surface area sprayed.

* Methods to uniformly collect data for this indicator are still under development.

6.3 Entomological indicators

The following are the definitions of the complete set of entomological indicators suggested for the surveillance, monitoring, and evaluation of malaria vectors in the Americas:

- **Presence of malaria vectors and species composition:** The primary malaria vectors for a given area may be known, however, it is important to know all the vector species present in intervention areas. Species should be initially identified based on morphological criteria utilizing published taxonomic keys. Due to the unclear taxonomic status of some species, molecular identification should be used in addition to morphological classification when necessary and feasible.

- **Spatial and seasonal distribution of vectors:** Understanding spatial distribution and seasonality helps to define the length of the transmission season and the peaks of biting behavior for each vector species. This information allows for greater understanding of malaria transmission dynamics over time and guides the planning and implementation of control measures.
- **Relative abundance:** The relative abundance of anophelines can be an indicator of the efficacy of vector control interventions. After the implementation of an intervention, a reduction in human-vector contact is expected. Mosquito density, as measured through human landing rates, is a good proxy measure of relative abundance. Regular monitoring of the relative abundance of species is needed so that control programs can respond appropriately to any significant increases in the main vector populations.
- **Feeding behavior:** Behavioral changes in mosquito populations after the introduction of insecticide-based control measures have been reported. For example, vectors can adopt more exophagic or more zoophilic feeding patterns to avoid indoor insecticide contact. Therefore, it is important to routinely monitor indoor and outdoor feeding behavior and, if possible, the human blood index (HBI) to detect changes in host preference.
- **Parous rate:** Mosquito survival and parous rates are important determinants of vectorial capacity and malaria transmission, and can be affected by insecticide-based interventions. This indicator assumes that the mosquito population is at equilibrium regarding gain and loss due to migration, breeding, and mortality. The bias resulting from a temporary reduction in parous rates due to a sudden increase in newly emerged mosquitoes may be minimized by pooling samples collected regularly over an extended period.
- **Insecticide susceptibility:** Determining the levels of susceptibility of the vector population to insecticides currently in use, or planned for use in the future, is of crucial importance to vector control programs. Ideally, baseline insecticide susceptibility data should be collected before an intervention is initiated and further data should be collected annually at a minimum, preferably at end of the transmission season. If resources are available, testing frequency can be increased or expanded in geographic range and the modes of action of insecticide resistance can be determined. The frequency of testing should be increased if there is an unexpected increase in the number of malaria cases or if insecticide resistance is suspected. Resistance surveillance should be performed at sentinel sites on all present malaria vectors.

6.4 Operational indicators

Insecticide-treated nets

ITN coverage surveys should be conducted in specific domains of interest, such as an area targeted for distribution campaigns, and not as part of a sentinel site-based methodology. This population-based approach will give more representative data on ITN ownership and use. This information will also inform decisions on the timing of net replacement. These surveys can include analyses of the content of insecticide and physical status of the nets in a subset of nets collected from the households visited. Protocols for such surveys are available from AMI partners and can be used as guidance for the development of future surveys.

- **Household coverage and use:** Household surveys are the preferred means of assessing household coverage and use of ITNs among populations at risk of malaria, and can signal if distribution plans have included adequate numbers of nets. In general, surveys should be conducted at regular intervals, e.g., every 6-12 months, to allow for up-to-date and reliable estimates on coverage and use.
- **Sufficient household coverage of ITNs:** As many countries are now favoring universal coverage over the coverage of vulnerable groups (children < 5 years old and pregnant women), there is a need to include indicators to assess if there are sufficient nets in targeted households.
- **ITN usage:** In addition to assessing the presence of ITNs in target households, it is important to determine if the ITNs are being used correctly. As a part of household coverage surveys, a simple questionnaire can be administered to household residents to document the proportion of individuals who slept under an ITN on the night preceding the survey.
- **ITN survivorship:** As countries often rely on ITN distribution via large-scale campaigns, malaria control programs should develop strategies to monitor the retention of ITNs after such campaign events. This information will assist in the planning of the timing of follow up campaigns and also assist in the development and implementation of strategies to maintain coverage levels for longer periods of time. Protocols and guidelines for this kind of monitoring appropriate to the region are currently under development and should be available in the near future.
- **Expected life span of ITNs:** Insecticidal activity and physical integrity. As countries scale-up to universal coverage of ITNs, it is critical to monitor the durability and insecticide content of nets. This provides valuable information about the duration of protection for the target population. Failure to replace ITNs in a timely manner can lead to increases in malaria cases.

In addition, if more than one brand of ITN is being used in a given region, it may be advisable to compare these ITNs and determine if one has a better profile in terms of durability. This information can be collected through surveys designed to evaluate nets at regular time intervals. They should be conducted in areas representative of particular cultural contexts and practices that may impact ITN life span, such as hanging and washing habits. These surveys do not need to be repeated as often as the coverage surveys unless changes in habits have occurred or are suspected. These surveys should include the measurement of insecticidal activity and/or insecticide levels as measured by the WHO cone bioassay and biochemical assays (simple colorimetric methods or high performance liquid chromatography) and physical integrity using standard inspection methods. Examples of previous evaluations of this kind are available from AMI partners upon request.

Indoor residual spraying

The use of a product for IRS with a lower concentration of active ingredient than that which is recommended can result in the application of a sub-lethal dose of insecticide. This can compromise vector control and could promote the development of insecticide resistance. Thus, it is recommended that vector control programs rely on WHOPES approved insecticides and purchase insecticides only from internationally recognized sources. IRS efficacy is also highly dependent upon the quality of the spraying procedure. To assess this, a subset of walls in houses should be evaluated with standard tests, such as the WHO cone bioassay, after each spray round. Care should be taken to evaluate the insecticidal effect of the insecticide used on the different possible types of surfaces because wall material and construction style can affect the efficacy of IRS.

- **IRS coverage:** Houses should be sprayed immediately before the onset of the transmission season and the number of houses sprayed in relation to the number of houses targeted should be recorded by spraying programs to estimate the initial coverage. In addition to the routine monitoring of the IRS operation, IRS coverage can be evaluated by independent surveys, such as Malaria Indicator Surveys, which can help to estimate the coverage of the spraying program.
- **Insecticidal effect on sprayed surfaces:** The expected efficacy of residually applied insecticide is dependent on its concentration and rate of decay on wall surfaces after application and can be measured using the WHO cone bioassay with a susceptible mosquito strain or wild-caught mosquitoes with no evidence of insecticide resistance. Monitoring should be conducted at regular 1- to 2-month intervals post-IRS in a selected subset of houses. This can provide information on how long the insecticidal effect lasts in a particular setting. For the first year, wall bioassays should be done monthly to determine the length of residual activity for a particular insecticide on the predominant wall surface types in the locale (e.g., mud, cement, or wood).

Once the residual lifespan of an approved insecticide is determined in a particular locale, it may be possible to decrease the frequency of the wall bioassays after subsequent spray rounds, or conduct only an initial assay immediately following the spray operation to confirm the quality of the spraying. The cone bioassay may be followed by chemical analysis if the IRS quality is still in doubt.

- **Dosage of insecticide:** It is important to ensure that the recommended dosage of insecticide is used. Personnel should compute the wall surface area to be sprayed and dosages should be calculated accordingly. Instructions on the sachet of insecticide should be used to determine the dilution application rate. Public health officials should base their dosages on international WHOPES recommendations. Guidelines for the evaluation of dosage are currently under development.

7

Monitoring plans per epidemiological strata

7.1 Moderate to low-transmission settings

Entomological indicators

Collection of information and frequency

The collection of entomological indicators should be done using a sentinel site-based approach. Data for the different indicators should be collected using standardized methodologies at regular intervals (a previously mentioned document[1] includes the description of a detailed protocol for the collection of entomological indicators in Latin America). Due to the behavior of the primary malaria vectors in the Americas, HLC are a preferred method for gathering entomological data for indicators related to to mosquito host-seeking behavior such as human landing rates and feeding behavior.

Figure 1 shows the proposed timing for data collection in areas of moderate to low malaria transmission. As a starting point, entomological surveillance should be conducted 3-4 times during the transmission season to collect data for those indicators related to mosquito presence and behavior. This accounts for the fact that vector abundances can change at different periods of the rainy/transmission season. By sampling at several points throughout the season, a comprehensive understanding of vector dynamics throughout the season can be obtained. Collection timing can be adjusted according to the seasonality and species composition of vectors in a given area, i.e., if a known vector is more abundant at the beginning of the transmission season, data on that particular vector should be collected then. At the end of the transmission season, the information gathered through entomological surveillance should be analyzed and taken into consideration when planning subsequent vector control activities, such as changes in insecticides used for IRS.

Data should be collected for the following entomological indicators:

- Presence of malaria vectors and species composition
- Spatial and seasonal distribution of vectors
- Relative abundance
- Feeding behavior
- Parous rate
- Insecticide susceptibility

Operational indicators

In areas with ongoing vector control, such as ITNs and IRS, the operational indicators listed in Figure 1 should be monitored as described previously.

Vector control

- **Objective:** To reduce malaria cases by either preventing vector-human contact or by reducing the population of infected mosquitoes.

- **Strategies available**
  -IRS (mass spraying or targeted spraying)
  -ITNs

- **Description of strategies:** Current vector control strategies employed in moderate to low-transmission settings include ITNs and IRS. Choosing between ITNs and IRS is quite often a matter of operational feasibility, availability of resources, and socio-cultural determinants. In addition, it is important to take into consideration vector behavior and insecticide susceptibility. In situations where malaria transmission is concentrated around limited foci, indiscriminate and widespread spraying may become less practical and cost-effective than then targeted or focalized use of IRS.

  The use of SR and combined ITN-IRS interventions are not formally recommended at this time due to the lack of evidence for any additional benefits resulting from their use in the Americas. The only situation in which IRS and ITNs should be considered for simultaneous implementation would be if pyrethroid resistance emerges. In such cases, it is recommended to continue with the use of ITNs and add IRS using an insecticide from a different class.

Figure 1. **Yearly timing of data collection for entomological and operational indicators in moderate to low transmission settings.**

		Indicators	Transmission season[1]					
			Month 1	Month 2	Month 3	Month 4	Month 5	Month 6
Moderate to low transmission	Entomological	Presence of vectors and species composition		•		•		•
		Vector distribution and seasonality		•		•		•
		Feeding behavior		•		•		•
		Relative abundance		•		•		•
		Parous rate		•		•		•
		Insecticide susceptibility						•
	Operational	Household ownership of ITNs*	•					
		Sufficient household ownership of ITNs*	•					
		ITN use*	•					
		ITN survivorship*	•					
		ITN insecticide levels*	•					
		ITN physical durability*	•					
		IRS coverage*	•					
		Insecticidal effect on sprayed surfaces*	•		•		•	
		Dosage and quality of insecticide*	•					

1 Transmission season length will vary based on the local context; for the sake of clarity, a 6-month transmission season has been represented in this table

* According to the control strategy in use

7.2 Low to very low-transmission settings

Entomological indicators

- **Collection of information and frequency:** As malaria transmission decreases, some of the indicators recommended for areas of moderate to low malaria transmission, such as those related to mosquito behavior, become less sensitive and more subject to bias, especially if data are collected at sentinel sites, which limits the catchment area of information. Therefore, in areas of low to very low malaria transmission, the recommended entomological indicators are reduced (Figure 2). The recommended indicators in these areas are those related to the presence and composition of vector species. In the event of a significant increase in malaria cases (i.e., outbreaks) and depending on the availability of personnel and resources, the determination of malaria infection rates and parity can also be included.
- As with other transmission levels, the collection of entomological data should be performed using a sentinel site-based approach with appropriate standardized methodologies, such as HLC. Sentinel sites should represent the eco-epidemiological settings present in the region. If possible,

the number of collection sites should be increased if a substantial rise in transmission occurs. Entomological indicators should be evaluated twice a year in areas of low to very low transmission as depicted in Figure 2.

Data for the following entomological indicators should be collected in areas of low to very low transmission:

- Presence of malaria vectors and species composition.
- Relative abundance.
- Insecticide susceptibility.

Operational indicators

In areas with ongoing vector control, such as ITNs and IRS, the operational indicators listed in Figure 2 should be monitored as described previously. The timing of these surveys is slightly different in low to very low-transmission areas.

Vector control

- **Objective:** Reduce malaria cases by either preventing vector-human contact or reducing the population of infected mosquitoes.

- **Strategies available**
  -IRS (mass spraying or targeted spraying)
  -ITNs

- **Description of strategies:** In areas with low to very low transmission and ongoing vector control with either ITNs or IRS, it is recommended that the strategy of choice be continued. If no vector control is in place, malaria control efforts should be focused on providing prompt diagnosis and treatment. Resources permitting, the implementation of a vector control strategy should be considered.

  In the Americas, malaria case detection, treatment, and reporting is fairly good. However, a reported increase in malaria cases in the routine reporting system in a given region should trigger an intensified vector surveillance and control response. While mass IRS may not be considered a feasible alternative, targeted or focal IRS should be considered.

Figure 2. **Yearly timing of collection of entomological and operational indicators in low to very low-transmission settings.**

		Indicators	Transmission season[1]					
			Month 1	Month 2	Month 3	Month 4	Month 5	Month 6
Low to very low transmission	Entomological	Presence of vectors and species composition		•				•
		Relative abundance of vectors		•				•
		Insecticide susceptibility						•
	Operational	Household ownership of ITN*	•					
		Sufficient household ownership of ITNs*	•					
		ITN use*	•					
		ITN survivorship*	•					
		ITN insecticide levels*	•					
		ITN physical durability*	•					
		IRS coverage*	•					
		Insecticidal effect on sprayed surfaces*	•		•		•	
		Dosage and quality of insecticide*	•					

1 Transmission season length will vary based on the local context; for the sake of clarity, a 6-month transmission season has been represented in this table

* According to the control strategy in use

7.3 Settings with no active transmission but risk of transmission

Areas with no malaria transmission, but at risk of transmission, are areas where no locally transmitted malaria cases have been reported in the last three years, but with competent vectors and the potential migration of individuals from regions with active malaria transmission. These also include areas where the possible emergence of new foci of malaria may occur after deforestation and subsequent land transformations.

The main malaria control activities in these regions are based on the early detection of human malaria cases. Early detection requires that there is a human surveillance system in place that will identify malaria cases rapidly once they appear.

Entomological indicators

Collection of information and frequency

Surveillance of entomological indicators and operational indicators should be conducted at sentinel sites representative of different eco-epidemiological situations. Indicators should be monitored every year during the period of the year of greatest mosquito abundance, i.e., the rainy season, and when there is a temporal succession of species capable of transmission (Figure 3).

Data for the following entomological indicators should be collected:

- Presence of malaria vectors and species composition.
- Insecticide susceptibility.

Operational indicators

Since no routine vector control strategy is in place, there is no need to monitor operational indicators as part of the routine monitoring and surveillance activities.

Vector control

- **Objective:** The role of vector control in areas with no malaria transmission is to prevent human to mosquito transmission and thus avoid outbreaks. In the event of locally transmitted malaria cases, vector control strategies will focus on containing and controlling transmission before it spreads.

- **Strategies available:** The regular use of large-scale vector control strategies such as ITNs and IRS is not recommended in areas with no malaria transmission. Options for preventing malaria transmission are personal protection (using ITNs, repellents, coils, or other methods to avoid mosquito bites), targeted or focal IRS, and SR of larval habitats susceptible to elimination.

  These strategies can be implemented via campaigns to promote the use of personal protection and ITN use. When malaria cases are clustered, focal IRS in affected areas should be conducted with an insecticide to which the mosquito population is susceptible, and ITNs (preferably LLINs) should be provided to all the population. In those regions with previously high coverage with conventional nets, bednet treatment campaigns could be considered as an alternative to LLIN distribution. Finally, if mosquito breeding sites are identified and are amenable to elimination, these can be targeted for SR.

Figure 3. **Yearly timing of collection of entomological indicators in settings with no active transmission but where the risk of transmission still exists.**

	Indicators	Rainy season (Months)					
		Month 1	Month 2	Month 3	Month 4	Month 5	Month 6
No transmis	Presence of vectors and species composition				•		
	Insecticide susceptibility				•		

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9

Annexes

Annex 1: **Malaria vectors in the Americas**

Anopheline species are deemed as primary and secondary vectors of malaria based on the presence of malaria parasites in salivary glands or by sporozoites detected by enzyme-linked immunosorbent assay (ELISA). The Americas have been divided into three main regions: Mesoamerica (Caribbean, Central America, and Mexico); Non-Amazon areas of Bolivia, Colombia, Ecuador, Peru, and Venezuela; and Amazon Basin areas of Bolivia, Brazil, Colombia, Ecuador, French Guiana, Guyana, Peru, Suriname, and Venezuela.

Sub-Region	Primary Vectors (species /species complexes)	Secondary Vectors (species/species complexes)
Mesoamerica	*Anopheles albimanus*	*An. vestitipennis*
	An. pseudopunctipennis	*An. darlingi*
		An. puntimacula
		An. apicimacula
		An. pseudopunctipennis
Non-Amazon	*An. albimanus*	*An. pseudopunctipennis*
	An. darlingi	*An. punctimacula*
	An. nuneztovari	
	An. aquasalis	
Amazon	*An. darlingi*	*An. benarrochi*
		An. oswaldoi
		An. rangeli
		An. triannulatus
		An. marajoara
		An. aquasalis
		An. deaneorum
		An. janconnae
		An. nuñeztovari
		An. braziliensis
		An. triannulatus
		An. peryassui

Annex 2: **WHO recommended insecticides for indoor residual spraying**

(source: http://www.who.int/whopes/Insecticides_IRS_Malaria_09.pdf)

Insecticide compounds and formulations (1)	Class group (2)	Dosage (g a.i/m2)	Mode of action	Duration of effective action (months)
DDT WP	OC	1-2	Contact	>6
Malathion WP	OP	2	Contact	2-3
Fenitrothion WP	OP	2	contact & airborne	3-6
Pirimiphos-methyl WP & EC	OP	1-2	contact & airborne	2-3
Bendiocarb WP	C	0.1-0.4	contact & airborne	2-6
Propoxur WP	C	1-2	contact & airborne	3-6
Alpha-cypermethrin WP & SC	PY	0.02-0.03	Contact	4-6
Bifenthrin WP	PY	0.025-0.05	Contact	3-6
Cyfluthrin WP	PY	0.02-0.05	Contact	3-6
Deltamethrin WP, WG	PY	0.02-0.025	Contact	3-6
Etofenprox WP	PY	0.1-0.3	Contact	3-6
Lambda-cyhalothrin WP, CS	PY	0.02-0.03	Contact	3-6

CS: Capsule suspension; EC: Emulsifiable concentrate; SC: Suspension concentrate; WG: Water dispersible granule; WP: Wettable powder.
OC: Organochlorines; OP: Organophosphates; C: Carbamates; PY: Pyrethroids.

Annex 3: **WHO recommended long-lasting insecticide-treated nets**

(source: http://www.who.int/whopes/Long_lasting_insecticidal_nets_Aug09.pdf)

Product name	Product type	Status of WHO recommendation	Status of publication of WHO specification
DawaPlus® 2.0	Deltamethrin coated on polyester	Interim	Published
Duranet®	Alpha-cypermethrin incorporated into polyethylene	Interim	Published
Interceptor®	Alpha-cypermethrin coated on polyester	Interim	Published
Netprotect®	Deltamethrin incorporated into polyethylene	Interim	Published
Olyset®	Permethrin incorporated into polyethylene	Full	Published
PermaNet® 2.0	Deltamethrin coated on polyester	Full	Published
PermaNet® 2.5	Deltamethrin coated on polyester with strengthened border	Interim	Published
PermaNet® 3.0	Combination of deltamethrin coated on polyester with s trengthened border (side panels) and deltamethrin and PBO incorporated into polyethylene (roof)	Interim	Under development

Notes:

1 Reports of the WHOPES Working Group Meetings should be consulted for detailed guidance on use and recommendations. These reports are available on the WHO homepage at http://www.who.int/whopes/recommendations/wgm/en/

2 WHO recommendations on the use of pesticides in public health are valid ONLY if linked to WHO specifications for their quality control. WHO specifications for public health pesticides are available on the WHO homepage at http://www.who.int/whopes/quality/newspecif/en