# Comprehensive Larviciding Evaluation and Assessment FRamework (CLEAR)

**The Malaria Elimination Initiative**

UCSF Institute for Global Health Sciences

The Malaria Elimination Initiative is an initiative of the UCSF Institute for Global Health Sciences.

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A framework for national malaria programs and their partners to evaluate the implementation, effectiveness, and cost-effectiveness of larviciding as a malaria control intervention.

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The Malaria Elimination Initiative (MEI) at the University of California San Francisco (UCSF) believes a malaria- free world is possible within a generation. As a forward-thinking partner to malaria-eliminating countries and regions, the MEI generates evidence, develops new tools and approaches, and builds consensus to shrink the malaria map. With support from MEI's highly-skilled team, countries around the world are actively working to eliminate malaria.

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# Acknowledgements

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# Key Terms and Acronyms

**Artificial Intelligence (AI):** Technology that enables machines to simulate human intelligence, including learning, reasoning, and self-correction.

**Cost-Effectiveness Analysis (CEA):** A method to evaluate the costs and benefits of public health interventions, comparing the cost to the health outcomes achieved.

**CDC Light Trap (CDC-LT):** A trap used to collect mosquitoes by attracting them with light.

**Comprehensive Larviciding Evaluation and Assessment Framework (CLEAR):** A structured approach to evaluate the implementation, effectiveness, and cost-effectiveness of larviciding as a malaria control intervention.

**Cluster Randomized Trials (CRTs):** A study design where pre-existing groups of individuals, termed clusters, are randomly allocated to different intervention arms to evaluate public health interventions.

**Community Engagement:** The process of involving local stakeholders in the planning, implementation, and evaluation of health interventions to ensure their relevance and sustainability.

**Disability-Adjusted Life Year (DALY):** A measure of overall disease burden, expressed as the number of years lost due to ill-health, disability, or early death.

**Difference in Difference (DiD):** A quasi-experimental design that measures outcome variables at two timepoints, in groups that receive the intervention and those that do not.

**Entomological Inoculation Rate (EIR):** The number of infective mosquito bites received per person per unit time.

**Entomological Surveillance:** Monitoring and analyzing mosquito populations to understand their density, behavior, and role in disease transmission to guide public health decision-making.

**Epidemiological Surveillance:** Monitoring and analyzing data related to the incidence and spread of disease within a population.

**Focus Group Discussion (FGD):** A qualitative research method that gathers information from a group of people about their opinions and experiences.

**Global Positioning System (GPS):** A satellite-based navigation system that provides location and time information anywhere on Earth.

**Human Landing Catch (HLC):** A method for collecting adult mosquitoes by having a person attract and capture them as they land to bite.

**Human Behavioral Observations (HBOs):** Observations that quantify human behavior during times that mosquitoes are active.

**Incremental Cost-Effectiveness Ratio (ICER):** A ratio that compares the cost-effectiveness of different interventions by dividing the difference in costs by the difference in health outcomes.

**In-Depth Interview (IDI):** A qualitative research method that involves detailed, one-on-one interviews to gather comprehensive information on a subject.

**Inhibition of Emergence (IE):** A measure of the efficacy of larvicides that prevent mosquito pupae from developing into adults.

**Implementation Trial:** A study conducted to evaluate the effectiveness and feasibility of an intervention in real-world settings.

**Indoor Residual Spraying (IRS):** The application of insecticides to the interior walls of dwellings to kill mosquitoes that encounter these surfaces.

**Insecticide-Treated Net (ITN):** A mosquito net treated with insecticides to kill mosquitoes and reduce malaria transmission.

**Key Performance Indicators (KPIs):** Quantifiable measures used to evaluate the success and efficiency of an intervention.

**Larviciding:** The regular application of microbial or chemical insecticides to water bodies or containers to kill mosquito larvae and pupae, aiming to reduce the adult mosquito population and thus disease transmission.

**Larval Source Management (LSM):** A strategy that targets mosquito larvae by modifying or treating their breeding habitats to control mosquito populations.

**Mapping Accuracy / Completeness:** A measure that verifies the accuracy and completeness of habitat mapping for effective targeting.

**National Malaria Program (NMP):** Government program dedicated to controlling and eliminating malaria within a specific country.

**Pre-qualification (PQ):** The process whereby manufacturers of a product submit a dossier of information on product quality, safety, and efficacy to WHO for rigorous evaluation to enable procurement by international organizations and to facilitate national registration.

**Resistance Management:** Strategies used to prevent or mitigate the development of resistance to insecticides among mosquito populations.

**Sub-National Tailoring:** An approach that involves customizing malaria control interventions based on specific local contexts and transmission patterns within districts or subdistricts.

**Unmanned Aircraft Systems (UAS):** Aircraft without a pilot onboard (e.g. drones).

# About the MEI Malaria Elimination Toolkit

The MEI Malaria Elimination Toolkit is a set of proven tools, frameworks, and guides to help malaria endemic countries accelerate progress toward malaria elimination. Developed by the Malaria Elimination Initiative (MEI) at the University of California, San Francisco (UCSF), the toolkit addresses the unique challenges faced by national malaria programs in heterogeneous transmission settings. These tools have been used successfully at the national and / or subnational levels, leading to important changes in malaria policy and practice.

The MEI Malaria Elimination Toolkit focuses on three primary areas: situation assessment, tailored responses, and program management and sustainability—with

the ultimate goal of building capacity and optimizing a country or district's ability to advance toward elimination. These tools help malaria programs understand the drivers of transmission in a target area and the readiness of the health system for elimination; decide what actions to take and how to tailor the response; and ensure efforts are well-managed and sustainably funded.

The MEI offers direct technical assistance to support the adoption, tailoring, and implementation of its tools, frameworks, and guidelines. Please contact us to learn more at mei@ucsf.edu, or visit our website at shrinkingthemalariamap.org.

## The MEI Malaria Elimination Toolkit

### Situation assessment

What are the drivers of transmission?
What is the readiness of the health system for elimination and what are the gaps?

### Tailored response

What actions should the program take based on identified and characterized gaps?

### Program management and sustainability

How does the program effectively manage and fund malaria elimination?

# Overview of CLEAR

To advance progress toward malaria elimination, innovation in both products and public health practice is essential. Global malaria policy has moved away from universal coverage of one or two interventions towards "sub-national tailoring"—an approach to customizing malaria control interventions based on district- or subdistrict-level stratification of malaria transmission. Within this evolving strategy, larviciding is increasingly prioritized by National Malaria Programs (NMPs) for its potential to complement existing Insecticide Treated Net (ITN) and Indoor Residual Spray (IRS) programs and fortify the overall vector control toolbox. Larviciding targets the immature aquatic stages of mosquitoes with insecticide, thereby reducing the number of adult mosquitoes that can transmit malaria. This approach offers distinct advantages, including the ability to control vectors in an unbiased way, as opposed to indoor-focused interventions which only target mosquitoes that exhibit certain behaviors as adults. This provides an opportunity to address residual malaria transmission in areas where ITNs and / or IRS are insufficient. Furthermore, larviciding can play a strategic role in insecticide resistance management by diversifying the active ingredients used in control.

The **C**omprehensive **L**arviciding **E**valuation and **A**ssessment F**R**amework (CLEAR) is designed to provide a structured approach to evaluate the implementation, effectiveness, and cost-effectiveness of larviciding as a malaria control intervention based on WHO recommendations, available evidence, best practices, and expert opinion. CLEAR builds on the WHO's larval source management operational manual (1) with a more detailed framework for monitoring and evaluating larviciding programs. CLEAR emphasizes the importance of context-specific data, community engagement, and technological advancements to enhance the operational and managerial aspects of larviciding programs. Use of the framework can help NMPs overcome strategic barriers due to evidence gaps, attract donor investment based on proven local effectiveness where relevant, and facilitate the successful scale-up of larviciding as a routine intervention to reduce mosquito populations, and thus malaria.

# Introduction

## What is CLEAR?

CLEAR is a framework for NMPs to design and evaluate larviciding interventions. CLEAR is not an operational guide for larvicide implementation, nor does it replace normative guidance on larviciding; rather, it is a complementary monitoring and evaluation framework. CLEAR also does not include other larval source management (LSM) approaches, such as environmental management or larvivorous fish, as these interventions require different evaluation considerations.

## Who should use CLEAR?

CLEAR is intended for use by NMPs, public health officials, public health researchers, implementation partners, and private sector organizations involved in malaria control and elimination efforts. The framework can be used by stakeholders seeking to integrate larviciding into their vector control toolbox through programmatic evaluation of small-scale pilots or large-scale implementation studies to generate robust evidence on the intervention's impact in local contexts.

## When should you use CLEAR?

CLEAR should be used when planning, implementing, and evaluating larviciding programs. It is especially useful during the initial design phase to ensure that the intervention is context-specific and data-driven. Additionally, CLEAR may be applied during implementation to monitor operational performance and assess community engagement, and to make appropriate adjustments. Finally, it may be applied during program review to ensure that measures of cost-effectiveness are incorporated in program decision-making.

## Why should you use CLEAR?

The WHO first recommended larval control as a supplementary measure in 2013 (1) and has since conditionally recommended larviciding in specific restricted settings where larval habitats are "few, fixed, and findable" (2). Technological advances in drones, remote sensing, and artificial intelligence are making this logistical hurdle more surmountable. As such, NMPs are increasingly looking for ways to support larviciding as a core component of integrated vector management strategies. A more explicit endorsement came with the *2022 Global Framework for the Response to Malaria in Urban Areas*, which highlighted larviciding as the recommended approach for malaria prevention, particularly in the context of controlling invasive *Anopheles stephensi* mosquitoes (3). Further recent publications (4,5) underscore the growing recognition of the role of larviciding as a component of comprehensive malaria control.

Despite the increasing global recognition and WHO recommendation, significant barriers continue to hinder the broader use of larviciding. Although some NMPs are investing their own public health budgets in larviciding, major donors have historically shown limited interest, instead favoring ITNs and IRS. Limited funding has restricted the scale, duration, robustness, and evaluation of larviciding activities. Other challenges include fragmented implementation experiences, inconsistent technical and policy support, and the inherent complexity of delivering and evaluating larviciding programs effectively. The lack of results-focused process and impact evaluation strategies results in ineffective planning and implementations, which are then repeated. Successful larviciding requires continuous improvement, which CLEAR can support.

Using CLEAR can help overcome these barriers by providing a framework for evaluating implementation, effectiveness, and cost-effectiveness. Ultimately, CLEAR aims to ensure that the full potential of larviciding for malaria control and elimination is realized, reigniting progress toward global malaria elimination goals.

# Module 1. Evaluation Design

## Logic Model / Theory of Change

**An important first step in developing an evaluation framework for a larviciding program is to define the logical sequence of events required for the intended outcome (a decrease in malaria burden) to be realized.**

A typical logic model for a larviciding program is presented in Figure 1. Arrows represent an "if…then" relationship. Developing a logic model as the foundation for an evaluation program is beneficial in multiple ways. First, it can help identify at what stage a program may fail, so that remedial actions can be taken immediately. In addition, it can help define the key data to be collected and the indicators to be calculated to fully understand the system.

The CLEAR framework assumes that the "Baseline data" section of Figure 1 has already been completed. It assumes that laboratory and other controlled small-scale trials have been completed, demonstrating that the product is effective against the targeted species and in the selected use case.

It also assumes that indicators about the product itself, as well as application strategies, have already been evaluated prior to implementation. For example, when a product undergoes pre-qualification (PQ) with the WHO or national regulatory authorities, rigorous assessments of safety, efficacy, and quality are conducted. This means that NMPs can be assured that products that are PQ-listed and / or approved by national regulators meet these standards, and they do not need to collect this data again. However, programs should be familiar with a chosen product's specification and other supporting documents to ensure that parameters that may impact product efficacy remain within the manufacturer's recommendations. NMPs (or their procurement agent)

would ideally verify selected physicochemical properties (e.g., content of active ingredient) to ensure that all batches of product received are within manufacturer-specified limits. For example, with ITN orders, procurement agents often inspect a sample of products to ensure key characteristics such as size, fabric / seam strength, active ingredient content, etc, are within the expected range provided by the manufacturer. Monitoring transport and storage conditions (e.g., temperature and humidity) is also important to ensure product quality is not compromised before use.

Finally, it assumes that thorough, up-to-date epidemiological, entomological, and environmental data are available to inform the selection of appropriate larvicides and targeting strategies.

The process and impact evaluation components of the logic model form the basis of CLEAR and are described in detail in Modules 2 and 3.

**Figure 1: Example logic model for a larviciding program**
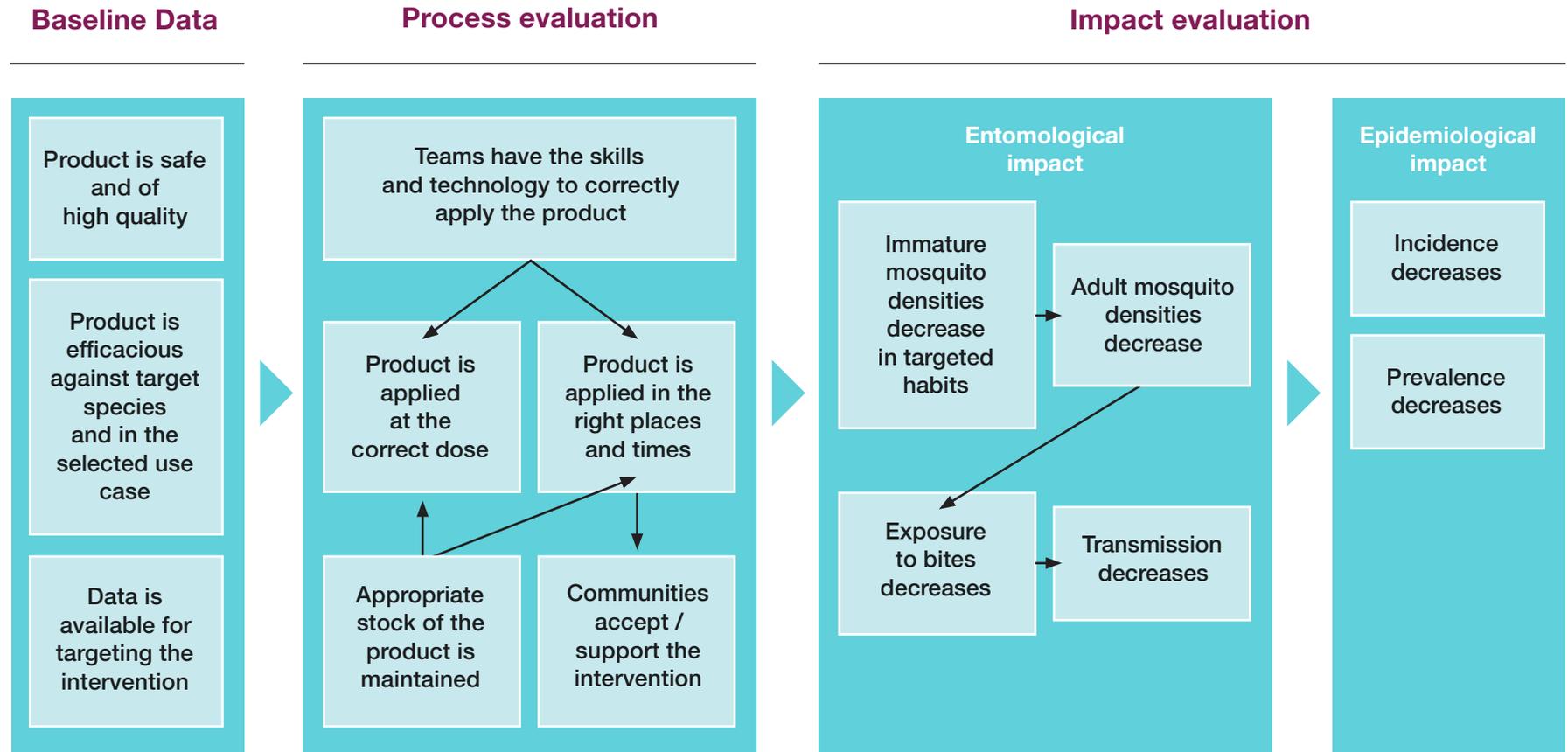
# Fundamental Principles

## Context-Specificity

Larviciding is highly context-dependent — its effectiveness is intrinsically linked to program capacity, the specific local environment, vector species, their ecological characteristics, and the nature and extent of water bodies. The global policy shift towards "sub-national tailoring" highlights that a universal larviciding approach is unlikely to be optimally effective or cost-effective across a country's diverse landscapes. Therefore, implementation research must explicitly aim to understand and demonstrate the context-specific effectiveness of larviciding. This goes beyond simply proving efficacy under ideal conditions; it involves understanding how the intervention performs under programmatic conditions, considering local vector biology, environmental factors, and human behavior.

## Question-based evaluation

The evaluation of larviciding programs depends on the specific questions being asked, as these dictate the indicators assessed and the methods used. For instance, questions focused on entomological impact might investigate reductions in abundance of adult mosquito populations and exposure to bites, whereas questions centered on epidemiological impact might examine decreases in malaria incidence or prevalence. Questions about process or program efficiency might analyse cost-effectiveness, coverage, operational feasibility, use of technology, or community acceptance. To ensure a comprehensive evaluation, it is essential to properly define the question(s) before developing an evaluation strategy. Below are some common questions NMPs may ask about their larviciding program.

**There will likely be multiple questions that a program is interested in answering, and the evaluation should be designed to answer all of them as efficiently as possible.**

- What is the effectiveness of the larvicide in controlling adult mosquito populations?
- What are the main community concerns to be considered in planning, implementation, and monitoring of larviciding?
- Which application methods will ensure optimum coverage of potential mosquito breeding sites?
- Is the larviciding program sufficient to reduce malaria incidence in protected areas?
- How does the cost-effectiveness of larviciding compare with alternative interventions?
- How efficient are larviciding operators in treating assigned habitats?
- What is the coverage of larviciding in targeted areas of District X?

## Operational Efficiency, Feasibility, and Scalability Considerations

The success of larviciding implementation depends on the efficiency, adaptability, and scalability of the delivery mechanism. Therefore, evaluation strategies should not only measure epidemiological and entomological outcomes, but also evaluate process metrics (e.g., coverage, timeliness, operator / team performance). Technological advancements offer promising solutions to overcome operational limitations. Digital tools, such as AI-based planning, GPS-based mobile applications, and online dashboards, can significantly facilitate the detection and treatment of larval habitats, thereby improving the operational and managerial aspects of large-scale larviciding operations. A larviciding pilot in São Tomé and Príncipe, for example, successfully leveraged such a system to guide fieldworkers, monitor real-time progress, assure quality (e.g., complete area scanning and proper application), and detect new larval habitats after rainfall (6). These tools are not just for data collection; they are crucial for optimizing intervention delivery and coverage in real-time, which is essential for large-scale operations.

## Importance of Community Engagement and Local Ownership

Community participation and ownership are critical for the long-term sustainability and success of larviciding interventions (7). Community engagement can take many forms, with community members actively involved in activities such as the design, mapping, delivery, monitoring, and evaluation of larvicide implementation. This approach fosters trust and transparency, increases efficiency because community members know their environment well, ensures the intervention is context-specific, and allows for local flexibility in implementation (8). CLEAR includes a section on community engagement methods and indicators in Module 3.

## Opportunities for Multi-Sectoral Coordination and Collaboration

Larviciding presents opportunities for broad coordination and collaboration across ministries and sectors as an intervention that fundamentally alters the environment within communities. Larviciding programs can partner with the agriculture sector, particularly with large-scale rice cultivation (9) and urban farms (10), to implement integrated pest management strategies that benefit both crop yield and public health. Implementation of larviciding for *An. stephensi* control in urban areas could provide added benefit in controlling arboviruses like dengue and zika that are transmitted by *Aedes aegypti*, fostering collaboration between different public health departments. Collaboration can also involve partnerships with civil engineering for infrastructure, environmental management authorities, and munici-palities / local leaders to address drainage issues and improve water infrastructure, thereby sustainably reducing mosquito habitats and achieving long-term disease prevention goals. The collective involvement of multiple sectors ensures a holistic, efficient, and sustainable approach to vector control.



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## Demonstrating Cost-Effectiveness for Sustained Investment

A key objective of the evaluation of larviciding implementation should be to conduct comprehensive economic evaluations that provide a more compelling case for sustained donor and national investment. Investing in robust data collection (e.g., precise georeferencing of households and larval habitats) and analytical expertise is crucial to demonstrate the full value of larviciding and secure the necessary financial and political support for scale-up. CLEAR includes guidance on cost-effectiveness methods and indicators in Module 2.

# Designing Your Larvicide Evaluation

The first step to evaluating your larvicide program is to decide on the appropriate evaluation design based on the program's question(s) and available monetary and non-monetary resources. In the following section, we describe design options that would form the basis for process (Module 3) and impact evaluation (Module 2).

This framework assumes that a program is either piloting larviciding in a small-scale implementation study or evaluating programmatic implementation of larviciding in a larger area. In either case, it is important to ensure that the implementation methods and data collected allow the program to answer key questions about the intervention. One of the most important components of public health programs is demonstrating whether there is a causal association between the intervention and health outcomes (e.g., does larviciding reduce malaria cases?). If the intervention does not reduce disease burden, this information can help the program consider optimized implementation strategies or decide on another intervention altogether.

Cluster randomized trials (CRTs) are a common study design in public health research where pre-existing groups of individuals, termed clusters (e.g., health facility catchment areas, villages, schools, or clinics), are randomly allocated to different intervention arms. Usually, CRTs have at least two arms: an intervention arm that includes the intervention being evaluated and a control arm that implements the standard of care. Multiple clusters are assigned to each arm. By comparing outcomes across arms in a CRT, public health researchers can generate robust, high-certainty evidence of the causal relationship between the intervention and desired outcomes.

**While CRTs are considered the "gold standard" for evaluating public health interventions delivered at a community level, they have several key limitations when implemented in a programmatic setting:**

- CRTs require that clusters be randomized between arms. However, programs typically target very specific areas with interventions (e.g., those with high burden). Therefore, randomization is usually not feasible.

- CRT design often requires many clusters (e.g., 20-30 or more) to achieve sufficient statistical power. In the context of malaria control programs, where districts or provinces are often the practical units of implementation, recruiting such a high number of independent clusters can be logistically challenging and resource-intensive.

- Larviciding interventions present additional challenges due to high heterogeneity in larval habitat distribution (and therefore in the intervention itself) and the greater significance of spill-over effects between clusters (e.g., mosquitoes emerging from untreated areas and flying into intervention areas). In addition, the resource-intensive nature of CRTs often prevents their implementation over long periods. Since larviciding is operationally challenging and requires programmatic experience to be implemented effectively, the impact in the first year of the intervention may not reflect its full potential.

## Quasi-Experimental Designs

Although CRTs provide the most robust evidence, they are often infeasible in operational settings due to limited resources and capacity or logistical and political constraints. The intent of this framework is to provide guidance on larviciding evaluation in programmatic contexts while retaining the benefits of a rigorous experimental approach. To that end, the following designs are considered quasi-experimental because they lack the key characteristic of randomization (Table 1). These types of designs may be more feasible than a CRT when randomization is not possible (e.g., large-scale interventions targeting a whole population, logistical or ethical challenges, or few implementation or control areas to choose from).

## Table 1. Quasi-experimental designs, ordered from least to most robust

| Presence of control | Design | Description | Strengths | Weaknesses | Graphical representation |
|---|---|---|---|---|---|
| **No control** | Before / After Study | Outcome variables are measured at one timepoint before and one timepoint after an intervention. | • Easy to implement<br>• Logistical feasibility<br>• Useful if you can't define a control group | • Doesn't account for changes in the outcome that would have occurred anyway (e.g., seasonal variation, unpredictable events)<br>• Usually only one follow up time-point, so can't capture continual improvement of program.<br>• not appropriate for the most robust impact indicator (incidence of malaria) | |
| | Interrupted Time Series | Outcome variables are measured at two timepoints (one before and one after the intervention), in groups that receive the intervention and those that do not. | • Useful if you can't define a control group<br>• Can capture variability due to improved operational performance over the years, depending on timelines | • Doesn't account for changes that would have occurred anyway<br>• Matching time before and after can limit weaknesses, but not eliminate unpredictable events | |

**Table 1** continued: **Quasi-experimental designs, ordered from least to most robust**

| Presence of control | Design | Description | Strengths | Weaknesses | Graphical representation |
|---|---|---|---|---|---|
| **Control** | (Non-equivalent) Control Group Design | Outcome variables are measured in a group that receives an intervention vs one that does not, usually measured at only one timepoint post-intervention | • Easy to implement<br>• Logistical feasibility | • Even if matching for important contextual factors, there is the potential for bias, as groups may differ in unmeasured ways that affect the outcome<br>• Usually only one measurement timepoint, so can't capture continual improvement of program.<br>• not appropriate for the most robust impact indicator (incidence of malaria) | |
| | Controlled Before/After Study using Difference in Difference (DiD) analysis | Outcome variables are measured at two timepoints (one before and one after the intervention), in groups that receive the intervention and those that do not. | • Accounts for unmeasured confounding variables present in both groups | • Usually only one measurement timepoint, so can't capture continual improvement of program.<br>• Not appropriate for the most robust impact indicator (incidence of malaria) | |
| | Controlled Interrupted Time Series (CITS) | Outcome variables are measured at multiple sequential timepoints before and after an intervention, in groups that receive the intervention **and those that do not.** | • Accounts for unmeasured confounding variables present in both groups<br>• Stronger causal inference | • Most intensive to implement due to multiple data collection points over many geographical areas | |

For all study designs with a control, it can be helpful to match baseline characteristics between the control and intervention areas. This limits the potential that external factors drive any changes observed in intervention areas. However, it may not be feasible to do this in a programmatic setting because NMPs may want to target interventions in areas with particular baseline characteristics (e.g., high malaria burden). In this case, unmatched control sites still provide a useful comparator. It may be useful for programs to combine different analyses for different outcome variables. For example, it may be feasible to do a CITS for adult mosquito densities, but a DiD for malaria prevalence in cross-sectional surveys.

The selected evaluation design will form the basis for the process and impact evaluation in Modules 2 and 3.

## Selecting a Larvicide

### When selecting a larvicide and formulation, several key factors should be considered:

1. Active ingredient: The chosen active ingredient should be based on proven efficacy against the target vector(s) and insecticide resistance data. Examples are provided in Table 2.

2. Habitat Characteristics: The chosen formulation must effectively reach the water's surface. For example, emergent vegetation can prevent liquid formulations that are deployed with sprayers from reaching the water's surface. Granules may be more appropriate in this situation. Further information on larvicide formulations is provided in Table 3.

3. Application Methods and Program Scale: Consider the size of larval habitats and the most appropriate application methods for each. Widespread small larval habitats across large areas are most efficiently treated with small-drop liquid sprays applied by Unmanned Aircraft Systems (UAS) or vehicle / backpack mist blowers. Direct application of tablets, briquettes, or granules is most efficient for residual control. Small ground pools can be efficiently treated by hand or power backpack distribution of granules.

4. Residual Efficacy: The frequency and cost of re-application are major considerations. Longer-lasting formulations, such as briquettes or granular slow-release products, reduce the logistical burden and cost of repeated applications. This is especially important for permanent or semi-permanent larval habitats. In circumstances where larval sources are ephemeral, residual products may not be as efficient as real-time application when sources are wet. Some formulations, however, offer residual efficacy in dry-down and re-flood scenarios.

5. Community Engagement and Safety: When involving community members in the application of larvicides, formulations that are easy and safe to handle without extensive training are preferred. In addition, the inherent human safety of the active ingredient should be considered, and appropriate mitigating actions should be put in place if appropriate. In addition, programs should consider the effect on non-target organisms and the environment, particularly in areas where water is used for drinking, agriculture, or fishing.

6. All of these factors need to be considered in the context of the product's cost and a measure of effectiveness. Unit costs of the product can be obtained from the manufacturer, but cost-effectiveness depends on the local implementation context and should be determined in any evaluation to inform future decisions. Further information on cost-effectiveness evaluation can be found in Module 2.

**Table 2: Larvicide type**

| Larvicide type | Mode of Action (MoA) | Examples |
|---|---|---|
| Microbial | Bacterial toxins attack larval midgut, leads to death | *Bacillus thuringiensis israelensis* (Bti), *Bacillus sphaericus* (Bs) |
| | Disrupts nervous system, leads to paralysis and death | Spinosad |
| Insect growth regulators | Inhibits molting or emergence to adult mosquito by interfering with development (juvenile hormone mimics) or inhibiting chitin synthesis | Methoprene*, pyriproxyfen (juvenile hormone mimics); diflubenzuron, novaluron (chitin synthesis inhibitors) |
| Chemical | Disrupts nervous system, leads to paralysis and death | Temephos, Pirimiphos-methyl |
| Surface films | Leads to suffocation and death | Polydimethylsiloxane (PDMS) |

*Currently undergoing WHO Pre-qualification (PQ) assessment

## Table 3: Larvicide formulation

| Formulation | Description | Considerations |
|---|---|---|
| Granules | Dry, porous particles coated with or containing the active ingredient. | Appropriate for many types of *Anopheles* habitats, including those with emergent vegetation because it can penetrate vegetation to reach the water. Easy to apply by hand or with spreaders. Can offer sustained release, providing longer residual efficacy. |
| Briquettes / Dunks | Solid, slow-release blocks that are placed in a water source and dissolve over time. | Appropriate for many types of *Anopheles* habitats, but particularly good for semi-permanent to permanent water sources that are difficult to access regularly, such as small ponds, wells, or water storage tanks. Long residual efficacy (weeks to months), reducing the frequency of re-application. Easy to handle and apply, making them ideal for community-based programs. May not be relevant for drone application. |
| Water-soluble Pouches (WSP) | Pre-measured, single-dose formulations of granules held in a pouch. The pouch dissolves in water, releasing the active ingredient. | Similar considerations as Briquettes / Dunks |
| Monolayer Films | A liquid that spreads a thin, physical film on the water's surface, suffocating larvae and pupae. | Appropriate for any clean water body with limited vegetation and water flow, and in sensitive environments like drinking water sources. Non-toxic and has a physical mode of action (suffocation), making it useful for resistance management. Efficacy is reduced by strong winds |
| Emulsifiable Concentrates (ECs) | Used with chemical insecticides. The active ingredient is dissolved in a solvent and an emulsifier. It forms a milky emulsion when mixed with water. Sprayed onto habitats. | Appropriate for clear and open water bodies. Provides rapid, uniform coverage over a wide area. The spray may not penetrate vegetation. The solvents can sometimes affect non-target aquatic life |
| Liquid formulations (liquid concentrates or wettable powders) | Often used for microbial insecticides. Concentrated liquid or powders that are dissolved in water. | Provides rapid, uniform coverage over a wide area. Penetration of vegetation depends on the application equipment used. |

# Module 2. Impact Evaluation

**A well-designed impact evaluation is critical to determine whether larviciding interventions are achieving their intended effects on vector populations and disease burden. It can generate the robust evidence necessary to inform policy decisions, attract sustained investment, and facilitate seamless integration into broader malaria control and elimination strategies.**

Impact evaluation examines whether larviciding contributes to changes in entomological indicators, disease transmission, and ultimately malaria burden in human populations. The key components of a comprehensive impact evaluation include assessments of entomological, human behavioral, and epidemiological indicators. Combined with cost data (also included in this module), programs can generate information to justify the allocation of scarce public health resources. The evaluation design selected in Module 1 would serve as the basis for evaluating these indicators.

## Entomological Impact

### Adult Mosquito Density and Species Composition

Reductions in adult mosquito densities, particularly among anthropophilic Anopheles, signal that the larviciding intervention is successfully reducing the overall transmission potential of malaria. Larviciding offers a distinct advantage over indoor-focused interventions like ITNs and IRS by being agnostic to adult host-seeking behavior (4). This makes it useful in addressing exposure from outdoor biting mosquitoes. Therefore, adult vector surveillance should include

sampling indoors and outdoors and explicitly differentiate between indoor and outdoor biting vectors to fully capture the intervention's complementarity with existing control strategies.

Collection methods for adult mosquitoes should be selected based on local vector behaviors, ethical considerations, and logistical feasibility. Human Landing Catches (HLCs) can be performed both indoors and outdoors to directly quantify human exposure to biting mosquitoes. CDC Light Traps (CDC-LTs) or tent traps are often also effective for collecting adult mosquitoes, but their use should be validated using local pilot studies. Comprehensive guidance on vector sampling, identification, and data analysis is available in MEI's Entomological Surveillance Planning Tool (11).

### Transmission indices

In the absence of other interventions, larviciding is expected to have minimal impact on Plasmodium sporozoite prevalence[1]. *This is because larviciding's primary contribution to transmission reduction is achieved by decreasing vector density, rather than by directly shortening their lifespan to prevent parasite development within them or by decreasing parasite density in the human population.* Other interventions, such as adulticides, enhanced case management, or chemoprevention, are designed to target these latter aspects. Although sublethal exposure to larvicides may reduce adult longevity, a well-implemented program aims to minimize such exposure. Therefore, any reduction in transmission is expected to be entirely due to a decrease in the size of the adult vector population, which is captured by monitoring adult mosquito density. For these reasons, sporozoite rate is considered a supplementary indicator in measuring the impact of larval control interventions. However, this data does enable the calculation of the entomological inoculation rate (EIR), a key metric that quantifies the number of infective bites per person per unit time. EIR is a widely recognized measure of transmission and can be valuable for comparing the magnitude of larviciding's impact to that of other control measures.

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1. The exception to this is in the short term (<14 days since intervention started) when sporozoite prevalence may temporarily increase as the age structure of the population shifts towards older individuals.

## Estimates of Exposure – Human Behavioral Input

The integration of human behavior data with entomological surveillance is increasingly recognized as crucial for understanding the effectiveness of interventions. Human Behavior Observations (HBOs), when combined with time-sequenced vector data (e.g., Human Landing Catches (HLCs)), can reveal temporal and spatial overlaps between mosquito activity and human presence—highlighting gaps in protection (Figure 2).

### Figure 2. Gaps in Protection
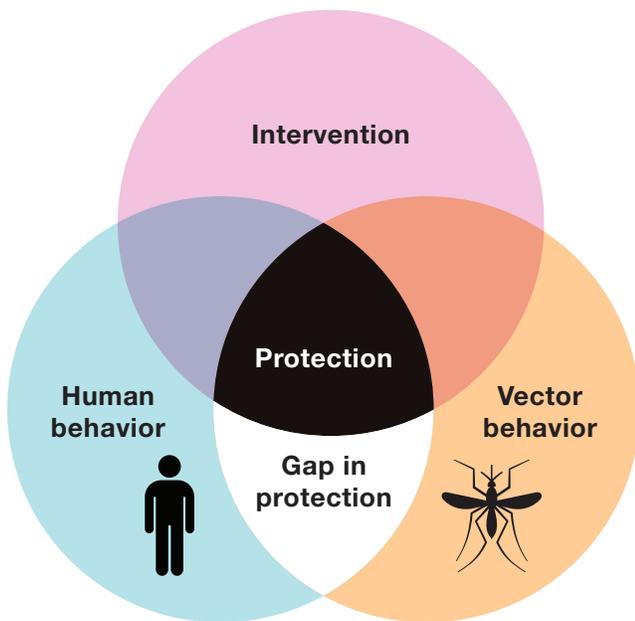


In larviciding programs, these analyses provide insight into changes in biting exposure relevant to program objectives. For instance, a program may implement a larviciding program specifically to reduce outdoor transmission, and they can quantify this by estimating exposure. Conversely, declining mosquito populations due to larviciding may reduce perceived nuisance, causing people to stop sleeping under bed nets and inadvertently increase indoor exposure. Therefore, exposure assessments are key to interpreting real-world program outcomes and should be included as a standard component of evaluation. Further guidance on integrating HBOs into entomological surveillance programs can be found in MEI's Entomological Surveillance Planning Tool (11).

## Sampling

The ideal entomological sampling design for larviciding evaluation includes paired HLC / HBO data collection throughout the hours of the day / night when humans are exposed to vectors, simultaneously in indoor and outdoor locations. In planning the location and frequency of these collections, programs should consider the following:

**Matched with epidemiological data in space / time.** Entomological data should ideally be collected from health facility catchment areas and over the same period as epidemiological data. This will make it more useful for explaining patterns in case data.

**Representativeness.** It is likely infeasible to collect data in every locality that receives the intervention or from which epidemiological data originate. Therefore, collections should be planned at locations and times that reflect the variability in mosquito biology and human behavior expected across the entire intervention area. For example, mosquito and human behavior and species abundances change from night to night (due to weather) and across seasons, so collections should be planned to capture this variability. This is often accomplished by planning several sequential nights of collection every month of the year. Similarly, there is geographic variation, both at the household level and at larger scales, driven by changes in ecological variables, so collections should be planned in locations that represent this diversity. This is achieved by randomly sampling several households within a locality and choosing several localities that represent the ecological zones being treated.

**Certainty.** Suppose a program wants to answer the question "Does larviciding significantly reduce adult mosquito biting density in intervention areas?" The program wants to demonstrate, with some level of statistical certainty, that adult mosquito biting is reduced. In this case, the required sample size depends on the expected magnitude of the effect (e.g., a reduction in biting by 50%), the baseline level of mosquito biting (or the level in the control arm, depending on the evaluation design), and the variability in the data (e.g., how different the catches are from night to night). Programs should consult a statistician if statistical certainty is important to them, given the technical nature of these calculations.

**Financial resources and logistics.** Ultimately, when / how frequently, and where to perform collections will be determined by the resources available. It is important to note that all data is useful, and focusing on data quality (rather than quantity) is critical.

## Epidemiological Impact

Ultimately, the goal of larviciding is to reduce the burden of malaria in humans. Measuring epidemiological impact requires thoughtful planning, the selection of appropriate indicators, and careful consideration of potential confounders and time lags, all of which are inherent to the study design described in Module 1. Two primary epidemiological indicators are typically measured in evaluations of vector control interventions: malaria incidence and malaria prevalence.

**Malaria incidence** measures the number of new malaria cases in a specific population per unit of time. Theoretically, incidence can be monitored through routine health facility data. If the intervention reduces disease burden, it will show up as a signal within a relatively short time frame (although see the discussion below on appropriate time lags). As a result, this allows incidence data to serve as a way for the program to gauge effectiveness quickly and respond accordingly. However, malaria incidence requires reliable, comprehensive systems for reporting new cases (Box 1). The quality and completeness of these data vary considerably and should therefore be validated through data quality audits to ensure their reliability for use in impact assessment. In addition, seasonal fluctuations in malaria transmission mean that incidence changes rapidly over time, even without an intervention. However, the impact of this confounding factor can be mitigated through appropriate evaluation design and analysis as described in Module 1. Enhanced epidemiological surveillance employed by some national malaria programs may also yield higher-quality incidence data that can be used to measure impact when the site(s) overlap with larvicide operations. Enhanced epidemiological surveillance involves strengthening the capacity of a network of selected health facilities to ensure that the data they collect are reliable, consistent, and available for decision-making (12,13). Regardless of which health facilities are selected as sources of incidence data, it is important that the entire health facility catchment area (in the intervention arm, if relevant) falls within the operational boundaries of the larviciding program, or that case data include the patient's specific residential location. This minimizes the possibility that cases from unprotected areas are included in the impact evaluation.

**Malaria prevalence** is the proportion of individuals who are positive for malaria parasites at a given point in time. It is commonly assessed through cross-sectional surveys. It provides a broad picture of the malaria burden, capturing all existing infections, whether symptomatic or not (depending on the diagnostic tool's sensitivity). Any impact of larviciding on malaria

## Box 1. HMIS data quality

While routine health management information system (HMIS) data offer a potentially rich source for impact evaluation, it has been underused due to significant concerns regarding its internal validity, completeness, and potential for bias. Key considerations include:

- Completeness of reporting: The number of reported cases can be lower than the true number of cases if the percentage of health facilities reporting in a given month is less than 100%

- Extent of diagnostic testing: The number of reported cases is affected by the extent of malaria diagnostic testing (e.g., number of slides examined or Rapid Diagnostic Tests (RDTs) performed)

- Inclusion of private facilities: Routine reporting systems often do not include data from private health facilities, leading to an incomplete picture of malaria burden.

- Overreporting and underreporting: Routine data in an HMIS can be subject to both overreporting and underreporting of incidence compared to register-based incidence. These systematic errors in data transmission from registers to higher reporting levels can bias impact estimates.

To gauge confidence in reported data and identify strengths and weaknesses of the reporting process, data quality audits (DQAs) at the service delivery level are crucial. However, conducting DQAs requires significant human and financial resources, which can limit their scope and scale-up.

Variable quality and completeness of routine case surveillance data directly influence the accuracy of incidence rates. If this data is unreliable, it becomes exceedingly difficult to confidently attribute observed changes in malaria burden to the larviciding intervention, even with the most robust study designs. This undermines the fundamental purpose of impact evaluation and the ability to make evidence-based policy decisions. Therefore, investment in data quality improvement and validation processes is as critical to the success of an evaluation as the intervention itself.

transmission would take longer to manifest as a signal in prevalence data. Compared to measuring incidence, which relies on routine health facility data, prevalence requires independent cross-sectional surveys, which necessitate dedicated survey infrastructure and teams.

Whether a program chooses to use prevalence, incidence, or both as endpoints for a larviciding impact evaluation depends on several factors, including the program's key evaluation questions, the selected study design (Module 1), the existing data infrastructure, and available resources. Key considerations are outlined in Table 4.

Malaria incidence is generally more appropriate for evaluating the immediate impact of an intervention on transmission. However, a national malaria program should also consider the feasibility of obtaining accurate incidence data and the potential benefits of complementing this with prevalence data to understand long-term effects.

## Table 4: Considerations in selecting epidemiological indicators

|  | Incidence | Prevalence |
| --- | --- | --- |
| Objective of the evaluation | Generally, more appropriate to assess immediate impact on transmission and symptomatic burden. | Generally, more appropriate to understand community-level malaria burden. |
| Data Infrastructure | Requires robust malaria case reporting system that produces reliable data. | Requires survey infrastructure, as well as the laboratory infrastructure to analyze samples if blood is collected by slide or dried blood spot. |
| Resource Availability | Continuous monitoring needed throughout the study period. May require additional resources for data quality audits if data quality is a concern. | Periodic, comprehensive surveys required independent of the routine health system. Frequency depends on the objective and study design, but two minimum (before / after). |
| Additional considerations | Appropriate for certain study designs – ITS or CITS. Aligned with standard cost-effectiveness methods (see below). | Appropriate for certain study designs – Before / After or Controlled Before / After. More difficult to incorporate into standard cost-effectiveness calculations. Results can be influenced by the diagnostic used and the seasonality. In low transmission settings, sample size needs to be very large. Compared to incidence, can take longer to detect changes in prevalence. |

By considering these factors, a national malaria program can make an informed decision on the most appropriate endpoint to use when evaluating the impact of larviciding interventions as part of its study design.

## Timing of Impact Assessment

Larviciding targets immature mosquitoes, leaving adult mosquitoes in the environment. Therefore, before a program evaluates impact, they need to wait for the adults that emerged just before treatment to no longer contribute to transmission. This lag period includes 14 days for the typical adult mosquito survival time plus approximately 14 days for the intrinsic incubation period of malaria in humans. Consequently, epidemiological assessment of larviciding impact should incorporate a conservative 30-day time lag post-intervention to accurately capture the intervention's impact on human malaria.

Failing to account for this time lag can lead to erroneous conclusions regarding an intervention's effectiveness. For instance, if impact is measured prematurely, a truly effective program might appear to have no effect or an underestimated effect, potentially leading to its premature discontinuation or the misallocation of resources. This underscores the need for methodological rigor in evaluation design, ensuring that data collection points are strategically timed to capture the true biological and epidemiological effects.

## Cost-Effectiveness Evaluation

### Key Concepts

Cost-effectiveness analysis (CEA) is a method for evaluating the costs and benefits of public health interventions by comparing the costs of an intervention to its outcomes, typically measured in terms of health benefits, such as cases prevented or lives saved. The Cost-Effectiveness Ratio (CER) is the ratio of cost per unit of health outcome (e.g., cost per case averted). When comparing a new intervention to an existing alternative, the Incremental Cost-Effectiveness Ratio (ICER) is employed. The ICER is a measure of the economic value of an intervention relative to an alternative. It is calculated by dividing the *difference* in total costs (incremental cost) by the *difference* in the chosen measure of health outcome (incremental effect). ICERs are particularly useful when a new intervention is more costly but yields improved health outcomes, helping decision-makers determine whether the greater effectiveness justifies the additional expenditure.

The perspective of the analysis is a fundamental determinant of which costs and benefits are included. Provider cost refers to the direct financial outlay incurred by the organization delivering the intervention, such as a NMP or a non-governmental organization. Societal cost encompasses the total economic burden to society, including provider costs, expenses borne by patients and unpaid care-givers, and other costs and effects extending beyond the healthcare sector. Adopting a societal perspective offers a more comprehensive representation of the intervention's overall economic impact but requires more detailed data collection. Provider cost analyses are typically more appropriate when conducted by NMP because they are easier to interpret and reflect the direct costs to the health system.

Health outcomes in CEA are commonly measured using standardized metrics. The Disability-Adjusted Life Year (DALY) is a composite metric often used to quantify the burden of disease. It represents the number of healthy life years lost due to disease or disability, and requires data on mortality, morbidity, and disability weights to calculate it. In CEA, health benefits are frequently expressed as DALYs averted, enabling comparisons across diverse interventions and diseases. When focused on malaria interventions specifically, cases averted is frequently used as an outcome measure. This metric is easier to calculate and interpret than DALYs averted, requiring only data on the number of cases, but it is not useful for comparing cost-effectiveness indicators across diseases. Both indicators require measuring health outcomes in intervention areas, along with the ability to estimate the same outcomes in a counterfactual scenario with no intervention.

The use of standardized outcome measures, such as DALYs or cases averted, is a powerful facilitator of comparative decision-making across disparate health interventions, such as comparing larviciding with vaccines or bed nets. By expressing health gains in a common unit, policymakers can directly compare the "value for money" of different investments. This ensures that scarce resources are allocated to interventions that yield the greatest health benefits per unit of currency spent, thereby transitioning from siloed program evaluations to a more holistic public health investment strategy.

## Interpreting Cost-Effectiveness

Unfortunately, there is no universally accepted standard for what constitutes a "cost-effective" intervention. Historically, a country's gross domestic product (GDP) has been used as a threshold, with an ICER of <1x GDP per DALY averted considered "highly cost-effective" and an ICER of <3x GDP per DALY averted considered "cost-effective." Originally proposed by WHO, these thresholds have been the subject of considerable criticism, even by WHO itself, because they are disconnected from opportunity costs, do not fully account for local budget constraints, and generally provide poor decision-making power because too many interventions are deemed cost-effective under these thresholds (14).

The absence of a universal cost-effectiveness threshold and its variation across countries and contexts reveal that cost-effectiveness is related to a country's economic capacity, its health system priorities, and its societal values. For instance, a lower-GDP country might consider an intervention highly cost-effective, with a much lower cost per DALY averted than a higher-GDP country. This implies that the decision to implement a particular malaria intervention must be determined not only by its effectiveness but also by the health system's ability to sustain its use. Therefore, while CEA provides a structured framework for evaluation, the ultimate decision-making process involves economic, political, and ethical considerations, requiring careful assessment of local context and affordability.

Cost per person protected is often presented as an indicator in vector control programs, and has been demonstrated to be similar between large-scale larviciding and ITNs / IRS (15). It can be useful when making decisions about where to target larviciding and which product to use. However, using this indicator in an impact evaluation can be misleading. A protected person, in the context of a larviciding intervention, could be defined as someone residing in a locality that was part of the intervention. However, whether that person is truly "protected" depends on numerous other factors, including coverage, dose applied, insecticide resistance, human behavior, and product quality, among others. Therefore, as a retrospective indicator of program effectiveness, it can give the illusion of success even if the intervention is poorly implemented or simply inappropriate for that context. In addition, it disregards the underlying malaria burden. In two localities with a

similar ratio of humans to larval habitats, the cost per person protected would likely also be similar. However, if one of those localities has a very high malaria burden, the program would be much more cost-effective there, preventing more cases.

## Calculating Cost-Effectiveness in the Context of a Larviciding Impact Evaluation

When conducting a CEA for a larviciding program, incremental costs and benefits are of most interest. This means measuring the additional cost to achieve an additional health benefit beyond what the standard-of-care already provides. A key principle of this approach is that if the standard-of-care costs are the same in both the intervention and control arms, they can be excluded from the calculation, as they will effectively cancel each other out. This approach simplifies data collection by focusing only on the resources specific to the new larviciding intervention.

From a provider perspective, the numerator of the ICER will be the total cost of the larviciding program. This should be a comprehensive figure that includes all resources consumed to implement the intervention and evaluate its impact.

Types of costs to collect include:

- **Intervention Costs**
  » Costs of mapping and enumeration – drones, software, staff time, fuel, etc.
  » Larvicide materials and supplies
  » Application equipment (e.g., sprayers, protective gear, drones)
  » Labor for larvicide application and management (e.g., salaries, wages, per diems)
  » Transportation and fuel costs to and from larval habitats
  » Stock / Inventory control
  » Implementation database

- **Evaluation**
  » Staff time for data collection and management
  » Technology costs, such as mobile apps and tablets for field data entry
  » Tech support for data collection devices
  » Database, data analysis, and report writing

Note that this has omitted the cost of any standard-of-care interventions (e.g., ITNs, diagnosis, treatment). The validity of this approach rests on a key assumption: that the cost of providing the standard-of-care intervention (such as ITNs) is the same per person in both the control and intervention arms. This is often a safe assumption if both groups receive the same type and quantity of ITNs under the same distribution method. However, larviciding could change the use of other resources. For example, if people in the intervention arm require fewer hospital visits or malaria treatments, then this "saved" cost would not be captured by this method. Program staff should evaluate any assumptions they are making when developing cost evaluation methods, preferably in consultation with a health economist, to ensure they are able to make informed decisions with the data being collected.

# Module 3. Process Evaluation

**Process evaluation is vital for understanding how an intervention is implemented and why it succeeds or fails. It helps distinguish between a program's failure to be implemented correctly and the intervention's failure to achieve its intended impact even when implemented well. Process evaluation is particularly important for larviciding programs because of their operational complexity.**

## Baseline Mapping

Larval habitat mapping and the establishment of a geospatial database are foundational to effective larviciding. A Geographic Information System (GIS) database

- provides a single source of information for the location, extent, and attributes of targeted habitats, creating the denominator for coverage calculations and enabling dose estimation based on surface area.
- links larval habitats to human settlements and health facility catchment areas, supporting targeting decisions and integration with entomological and epidemiological datasets.
- enables operational planning (e.g., routing, crew assignments, drone flight plans) and real-time performance monitoring.

Various techniques can be used to build the GIS: hydrological models (16), remote sensing, community knowledge, and field verification. Hydrological modelling can help identify broad areas to target the intervention. High-resolution satellite or drone imagery, combined with AI-assisted detection, can be used to generate candidate water features within the intended operational radius around human habitation (17). Community-led

mapping can leverage local knowledge of cryptic habitats or seasonality and build local ownership. GPS- and AI-enabled mobile applications (6) can help field teams confirm ecological suitability for *Anopheles*, delineate boundaries as polygons to compute surface area, and capture standardized attributes (habitat type, permanence, vegetation, flow, turbidity) and photographs.

## Larviciding Coverage

### The Dynamic Nature of Coverage

The success of a larviciding program relies on achieving high coverage of larval habitats, defined as the number or surface area of targeted larval habitats that are treated. However, defining and measuring coverage can be challenging due to 1) the varying residual life of larvicide products, and 2) the ephemeral and cryptic nature of many larval habitats. This means that coverage can change drastically over a single transmission season. Imagine the following scenario using a larvicide with 4-week residual activity (Table 5). In the first 3 months, the number of larval habitats to target for treatment is increasing, but the number treated remains consistent, perhaps because the teams are only retreating the same habitats they originally mapped. By month 4, they start to treat more sites, but not enough to keep up with the growing number of larval habitats. In this case, coverage varies from 67%-100% over a single season.

## Table 5: Example dynamic coverage of larviciding program over 6 months

| Month | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Treated habitats | 28 | 25 | 28 | 35 | 35 | 35 |
| Targeted habitats | 30 | 25 | 42 | 50 | 40 | 38 |
| Coverage | 93% | 100% | 67% | 70% | 88% | 92% |

This challenge is equally important when using products with longer residual activity, like some insect growth regulators. Programs should not assume that the coverage they achieved with the first treatment will remain consistent throughout the season. It is therefore necessary to remap sites at intervals frequent enough to respond to the local dynamics of the targeted larval habitats. The dynamics of targeted larval habitats (i.e., how frequently they appear or dry up over the course of the intervention period) can be determined by baseline longitudinal entomological surveys. Based on this data, a program may decide to remap every month if targeted habitats are ephemeral, or only once per season if they are permanent. Re-mapping can be combined with re-treatment activities if the intervals are aligned. Coverage should be calculated on a rolling basis, with a minimum coverage target for each measurement period.

### Definition of Targeted Habitats

The definition of a habitat targeted for larviciding is important because it comprises the denominator in coverage calculations. Several factors should be considered when developing a definition of a targeted site:

**Proximity to humans:** Since *Anopheles* breed near humans, targeted larval habitats should fall within a defined radius of human dwellings or nighttime activity sites (e.g., work or agricultural sites). This radius could be guided by the species' typical flight range (e.g., 1-2 km for many *Anopheles*). It has been demonstrated that approximately 90% of all adult *An. gambiae s.s.* originate from habitats within 1.7km of the location of host seeking (18).

**Ecological suitability:** Efficient larviciding programs should prioritize habitats that are ecologically conducive to *Anopheles* larval development. Many species of *Anopheles* (although not all) prefer clean, shallow, sunlit, stagnant or slow-moving water bodies, often with emergent vegetation. This contrasts with *Culex, Aedes,* or *An. stephensi* mosquitoes, which may prefer more polluted or container-based habitats. Defining targeted habitats based on specific ecological preferences identified through entomological surveys or historical knowledge ensures that efforts are focused on productive larval habitats. Trained AI models can accurately identify suitable larval habitats from images.

**Productivity:** Within those sites that are ecologically suitable, there is a huge range of productivity between larval habitats that is governed by numerous factors depending on the vector species, including algal content, dissolved nutrient levels, vegetation, surface area, natural predators / competitors, sunlight, pH, and turbidity, among others. This means that relatively few suitable habitats may be contributing most of the adult mosquitoes (19). It is therefore important that the program either identify the most productive habitats or efficiently treat all habitats. Coverage calculated by surface area (in addition to the number of habitats) can be helpful to better understand the percentage of total available habitat that has been treated.

## Additional Considerations

Operational intricacies further complicate coverage calculations. For example, what happens if a team does not scan / map a certain part of a targeted area? What if a larval habitat is "missed" in the mapping process? Both scenarios are common, meaning there are potentially productive habitats the program is blind to, which results in inflated coverage metrics. For these reasons, it is recommended to conduct quality control scans, in which an independent team or supervisor verifies the mapping results. Quality control scanning may be implemented systematically across the program or initiated in response to data gathered on team performance (see section below). For example, data may indicate that one team member maps significantly fewer sites in a given area than the rest of the team. In this case, it may be prudent to target that individual for quality control checks and retraining. It is important that these quality control activities are performed by individuals separate from those performing the mapping or treatment to limit bias in the quality control data.

## Operational Performance

Monitoring the performance of both ground-based teams and drone operations (if relevant) is essential for ensuring effective larviciding operations and efficient resource management. It helps to identify issues and associated actions for immediate improvement.

## Key Performance Indicators (KPIs) for Teams

Key Performance Indicators (KPIs) are quantifiable measures that track how effectively and efficiently field teams perform their duties. For larviciding programs, these indicators should focus on the quality of work performed and the actions the program can take. Most of the KPIs in this section assume that larvicide is applied directly to the habitat by an operator, but they may also be applicable to drone-based delivery mechanisms.

### Larvicide Dosage Accuracy

Proper dosage of larvicide ensures optimal efficacy and prevents the development of resistance or environmental concerns. Initially, personnel training and calibration / characterization of application equipment are essential to minimize over- or under-dosing. In addition, during implementation, dosage accuracy should be monitored. This is a quality metric that measures the consistency and correctness of larvicide application. It is calculated by comparing the actual amount of larvicide used by a team member or drone against the surface area of the habitats they have treated. This allows programs to determine the precise dose of insecticide applied to habitats, which is directly relevant to the intervention's potential effectiveness. If a team member or drone is consistently under- or over-applying insecticide, this data can inform targeted retraining activities or equipment checks. At a geographic level, this KPI can be aggregated to reflect the percentage of habitats that have received the appropriate dose.

### Immature Entomological Data

Quantification of larval and pupal densities is a direct method for assessing the effects of larviciding on mosquito early life stages. The specific metrics employed must align with the larvicide's mode of action. For microbial larvicides such as Bti, late-stage larval (L4) and pupal density measurements are appropriate, as these compounds induce acute mortality within ~24 hours. Evaluation based on 48-hour post-treatment surveys is appropriate for Bti and slower-acting Bs. Immature density can be measured by dipping a ladle into a habitat and counting the number of larvae / pupae collected, ensuring that the size and number of dips remain consistent. In contrast, for insect growth regulators (IGRs) like methoprene or pyriproxyfen, metrics such as inhibition of emergence (IE) are more meaningful, since these products typically prevent the transition of mosquito pupae to adults. IE can be measured by collecting pupae or late-stage larvae from habitats, transporting them back to a local insectary, and quantifying the proportion that successfully emerge as adults. Although it is infeasible to perform these surveys in every treated habitat, it is important to implement this as part of standard quality control checks in a sample of habitats. If the program is interested in verifying residual efficacy in operational conditions, then immature collections should be performed at regular intervals (e.g., weekly) between treatments. Tracking the time it takes for the first pupae to appear can help determine the most efficient time to re-treat.

Data derived from immature mosquito surveillance indicate both process effectiveness and biological performance. Persistently elevated larval or pupal densities post-treatment can signal operational deficiencies, such as insufficient habitat coverage, incorrect application, or inappropriate re-treatment intervals. Furthermore, such data can reveal biological performance challenges, including the emergence of insecticide resistance within the local vector population or unanticipated interactions between the product and the environment. Because immature mosquito stages precede the emergence of adult mosquitoes and, subsequently, the occurrence of human malaria cases, a failure detected at the larval stage provides an early

indication that the intervention may not achieve its intended impact on human disease. This allows for prompt, proactive remedial actions, such as retraining field teams, reassessing product efficacy, or re-mapping habitats, before program deficiencies manifest as an increase in malaria cases.

### Treatment Success Rate

Treatment success rate is an indicator of a larviciding operator's efficiency in treating the habitats assigned to them on any given day. It is calculated by dividing the number of habitats successfully treated (yes / no) by the total number of habitats assigned to that operator on that day. It requires very detailed habitat maps, structured task assignments, and accurate daily collection of data on treatment activities. A high rate indicates efficient application, reducing the need for follow-up visits. A low rate may indicate that an operator is not effectively locating their assigned habitats, there is a low stock of insecticide, or that there are accessibility issues, all of which require follow-up by a supervisor to ensure efficient operations.

### Mapping Completeness

The completeness of habitat mapping is critical for effective targeting. Quality control scans by supervisors (ground truthing) can verify mapping results, whether from ground teams or drone surveys, indicating areas where teams might be underperforming in habitat identification. This indicator is calculated by dividing the number of habitats mapped by a team member by the number of habitats present (as verified during quality control visits).

### Considerations for Large Area Applications

There are many types of equipment that programs can use for larviciding depending on the context and use case. For example, wide-area applications are available that use specialized atomizer equipment to produce very fine droplets that can reach and settle in cryptic habitats. Wide-area applications are typically delivered from truck-mounted equipment but can also be mounted on aircraft or as a backpack. In addition, UAS applications are increasingly being adopted for malaria vector control in large areas, such as rice paddies (20). Selecting process evaluation metrics for these types of applications depends on the method and use case. For example, if a program uses drones for insecticide application or habitat mapping, it is important to monitor how well the drones adhere to their pre-planned flight paths. Any significant deviation from a flight path could indicate an equipment malfunction and may need to be re-run. The same principles apply to truck-mounted

or aircraft delivery, and use of these methods requires a thorough understanding of the equipment's swath characteristics, application path, lane separation, and the effects of wind. It is recommended that programs seek guidance from equipment manufacturers on suggested performance metrics and how to interpret them.

### Insecticide Resistance

Although not strictly an indicator of operational performance, monitoring resistance to the larvicide used by the program can help distinguish an operational failure from a biological one. For example, if quality control checks reveal that larvae are not declining in density after treatment, this could be due to poor application by field teams, poor formulation or improper storage of the product, or the development of resistance to the product. To account for this, programs should regularly monitor resistance to all active ingredients used by the program (or being considered for future use). This is done by exposing F1 larvae (e.g., the larvae from wild gravid females) to diagnostic concentrations of larvicides and recording mortality or inhibition of emergence. Protocols for completing these bioassays are available on the WHO website (21).

## Technology to Support Efficient Process Evaluation

The WHO recommends prioritizing larviciding in aquatic habitats that are "few, fixed, and findable," emphasizing the importance of clearly delineated, stable, and identifiable larval sites that can be reliably located and treated. However, in many malaria-endemic settings, the heterogeneity of aquatic habitats poses a challenge to meeting this criterion. Recent technological innovations can help overcome these limitations, making habitat identification, monitoring, and treatment increasingly attainable.

Digital tools such as GPS-enabled mobile applications have transformed field operations by enabling real-time mapping, task assignment, and data capture. These tools can record habitat boundaries and treatment events with high positional accuracy, automatically linking operational data to georeferenced records (6). This capability supports the process indicators described earlier (e.g., dosage accuracy, coverage, mapping completeness, treatment success).

Drone-based mapping and insecticide delivery are increasing the feasibility of large-scale habitat detection and treatment. High-resolution drone imagery can reveal cryptic or inaccessible breeding sites that might otherwise go unnoticed. When integrated with AI

**Drone Mapping and Application**

**Remote Sensing**

**Hydrological Modelling**

**Technology to support larviciding programs**

**GIS & Mapping**

**Monitoring Dashboard**

**Mobile Apps for Field Operations**

and computer vision algorithms, such imagery can be automatically analyzed to identify water bodies with characteristics consistent with *Anopheles* breeding habitats. These AI-based detection systems have already demonstrated strong agreement with manual mapping approaches and can help ensure that larval habitats remain "findable" even in complex environments (17).

Hydrological modelling can predict where and when potential larval habitats are likely to form. Models incorporating rainfall, soil type, and topography can accurately simulate the spatial distribution and persistence of water bodies relevant for mosquito breeding. When calibrated with local data and remote-sensed inputs, such models can guide larviciding efforts toward areas likely to have the greatest impact, enhancing efficiency and ensuring resources are directed to the most relevant areas (16).

Finally, integrating these data streams into digital dashboards enables continuous monitoring and feedback loops between field and management levels. When process evaluation indicators fall outside the desired range, supervisors can implement remedial measures immediately.

## Community Engagement

Community involvement is increasingly recognized as a critical element for the success of malaria programs (8). Communities are vital to effective larviciding programs, given their knowledge of local contexts

and environments. Larviciding is also labor-intensive, so community participation in larviciding is essential to ensure its feasibility, ownership, and long-term sustainability. However, the level of engagement depends on the structure of the larviciding program, and how to evaluate that engagement depends on the desired outcomes.

### Spectrum of Community Engagement

The International Association for Public Participation (IAP2) outlines a spectrum of community engagement (22) (Table 6). While "informing" and "consulting" achieve basic awareness or gather initial feedback, the deeper levels of "involve," "collaborate," and "empower" build ownership and lead to more sustainable programs. Compensating community members becomes increasingly important at higher levels of engagement to support genuine partnership; a good example of a community-led larviciding program with paid workers is the Urban Malaria Control Program in Tanzania (23). Although many larviciding programs operate through a "top-down" approach, a strategic shift towards greater community engagement is required to ensure sustained effort and adaptation to local contexts. Programs should therefore assess which level of engagement is appropriate for different aspects of larviciding, for example, informing about product safety versus co-leading habitat mapping and treatment schedules. Achieving deeper engagement requires dedicated resources, time, and a willingness to share power, but it yields greater long-term impact and resilience against challenges such as misinformation or resource constraints.

## Table 6: Spectrum of Community Engagement (22)[2]

| Community Engagement Level, from least to most engaged | | | | | |
|---|---|---|---|---|---|
| | **Inform** | **Consult** | **Involve** | **Collaborate** | **Empower** |
| Public Participation Goal | To provide the public with balanced and objective information to assist them in understanding the problem, alternatives, opportunities and / or solutions. | To obtain public feedback on analysis, alternatives and / or decisions. | To work directly with the public throughout the process to ensure that public concerns and aspirations are consistently understood and considered. | To partner with the public in each aspect of the decision including the development of alternatives and the identification of the preferred solution. | To place final decision making in the hands of the public. |
| Promise to the Public | We will keep you informed. | We will keep you informed, listen to and acknowledge concerns and aspirations, and provide feedback on how public input influenced the decision. | We will work with you to ensure that your concerns and aspirations are directly reflected in the alternatives developed and provide feedback on how public input influenced the decision. | We will look to you for advice and innovation in formulating solutions and incorporate your advice and recommendations into the decisions to the maximum extent possible. | We will implement what you decide. |
| Example Activity in a Larviciding Program | Health Education Campaigns. Disseminating information on mosquito larval habitats, the importance of larviciding, and how to identify larvae through posters, radio messages, or community meetings. | Gathering local perspectives on perceived larval habitats, preferred larviciding methods, or potential challenges before program implementation. | Training local volunteers to identify and map larval habitats using mobile apps, or organizing community clean-up campaigns for source reduction. | Joint Planning Workshops: Community leaders, health workers, and program staff co-design larviciding schedules, select appropriate larvicide products, or decide on community-led application strategies. | Communities take joint or full responsibility for procuring larvicides / financing, organizing application teams, and mapping and monitoring local larval habitats, with external programs providing technical support and oversight. |
| Example Desired Outcomes | Increased community awareness and knowledge about malaria transmission, larval habitats, and larviciding as a prevention tool. | Understanding of community needs, preferences, and potential barriers. Feedback from community shapes program design. Interventions are culturally relevant and contextually appropriate. | Active participation in data collection, intervention implementation, environmental management, etc. | Shared decision-making, increased ownership. | High levels of local ownership and sustainability; community-driven problem solving and adaptation. |

## Indicators and Measurement

Table 7 provides some examples of relevant indicators for community engagement and how to measure them. Programs should select indicators relevant to their program goals.

**Table 7: Examples of indicators for community engagement**

| IAP2 Level of Engagement | Potential Indicators | Methods of Measurement |
|---|---|---|
| Inform | • Awareness of malaria transmission routes<br>• Awareness and support / acceptance of programmatic activities<br>• Knowledge of mosquito larval habitats and larviciding methods<br>• Recall of program messages (e.g., posters, radio ads)<br>• Perceptions of larvicide product safety<br>• Reach of information campaigns (e.g., number of attendees) | • Household Knowledge, Attitudes, and Practices (KAP) surveys<br>• Focus group discussions (FGDs)<br>• Interviews with community members<br>• Attendance logs at community meetings; distribution records of materials |
| Consult | • Number and diversity of community members providing feedback (disaggregated by gender)<br>• Integration of community feedback into program design / revisions<br>• Satisfaction with consultation process<br>• Perceived understanding of community needs and preferences | • Records of community meetings, workshops, and feedback sessions<br>• Review of program planning documents and implementation protocols; comparison of initial plans vs. revised plans<br>• Post-consultation surveys or exit interviews<br>• FGDs and in-depth interviews (IDIs) with program staff and community leaders |
| Involve | • Number of community volunteers participating in activities (disaggregated by gender)<br>• Frequency and consistency of community participation<br>• Accuracy of data collected by community members (e.g., mapping)<br>• Number of larval habitats identified / treated by community teams<br>• Community contributions to source reduction efforts | • Volunteer registration lists and activity logs<br>• Observation of field activities; attendance records for training sessions / clean-up campaigns<br>• Verification checks of data collected; comparison with expert assessments<br>• Program monitoring reports; GPS data from mapping activities<br>• Visual assessments of environmental cleanliness; records of clean-up events |

**Table 7** continued: **Examples of indicators for community engagement**

| IAP2 Level of Engagement | Potential Indicators | Methods of Measurement |
|---|---|---|
| Collaborate | • Jointly developed work plans or schedules<br>• Shared decision-making on program components (e.g., product selection)<br>• Perceived ownership of the program by community leaders / members<br>• Resource mobilization through shared efforts<br>• Conflict resolution mechanisms established | • Review of meeting minutes and signed agreements / memos of understanding<br>• Documentation of decision-making processes; interviews with joint committee members<br>• FGDs and IDIs with various stakeholders (community, program staff)<br>• Financial records<br>• Observation of joint meetings; records of conflict resolution processes |
| Empower | • Community-led identification of mosquito larvae and habitats<br>• Community-initiated larviciding activities<br>• Financial contributions or resource allocation by the community<br>• Community-managed monitoring and evaluation processes<br>• Autonomy in decision-making and problem-solving at the local level<br>• Sustainability of program activities beyond external support<br>• Adaptability to changing local contexts | • Case studies of community-led initiatives; program reports on independent community actions<br>• Case study of community-led initiatives for mapping mosquito larval habitats<br>• Financial records<br>• Review of community-generated reports; observation of community-led data collection<br>• Interviews with community leaders; observation of decision-making forums<br>• Longitudinal studies; assessment of program continuation post-withdrawal of external funding<br>• Analysis of how communities modify strategies in response to new challenges |

# Summary Indicators and Conclusion

A summary of all the suggested indicators discussed in CLEAR is available in Table 8. By combining standardized measurement approaches with robust surveillance designs that limit the influence of confounding factors, programs can generate evidence that is not only relevant to inform local decision-making but also contributes to the wider body of knowledge on the effectiveness of larviciding for malaria prevention.

## Table 8: Key Indicators for Larviciding Programs and Measurement Methods

| Evaluation type | Category | Indicator | Calculation | Description / Relevance | Measurement Method(s) | Key Considerations |
|---|---|---|---|---|---|---|
| Impact | Entomological | Species-specific Adult Mosquito Biting Rates* | Average number of mosquitoes captured per unit of collection effort, usually expressed as bites / person / night or bites / person / hour | Reduction signals decreased transmission potential. Can be used in subsequent calculations of gaps in protection (see below) | Examples include Human Landing Catches (HLCs), CDC Light Traps (CDC-LTs) with morphological or molecular identification | Distinguish indoor / outdoor biting; align with local vector behavior. Important for understanding impact on targeted vs. non-targeted species |
| | | Entomological Inoculation Rate (EIR) – supplementary indicator* | Average mosquito biting rate x proportion of mosquitos positive for sporozoites, usually expressed as infective bites / person / year | Quantifies infective bites per person per unit time. | Calculated from adult biting rates and sporozoite rate, measured by ELISA | Sporozoite rate not impacted by larviciding alone, and is usually a small percentage, so large sample sizes aer needed. Potential valuable for comparing magnitude of impact with other interventions. |
| | Human Behavioral | Adjusted Human Landing Rates* | Biting rate in a particular location and time x proportion of people exhibiting relevant behaviors at that location and time | Quantifies overlap between mosquito and human activity and gaps in protection. | Human Behavior Observations (HBOs) combined with HLCs | Detects changes in exposure due to human or vector behavior |

*For more details on these indicators, please consult the ESPT (11)

## Table 8 continued: Key Indicators for Larviciding Programs and Measurement Methods

| Evaluation type | Category | Indicator | Calculation | Description/ Relevance | Measurement Method(s) | Key Considerations |
|---|---|---|---|---|---|---|
| Impact continued | Epidemiological | Malaria Prevalence | Number of individuals positive for malaria / number of individuals surveyed | Proportion of individuals positive for malaria at a point in time. | Cross-sectional surveys | Requires dedicated survey; consider seasonality and frequency.<br><br>Not appropriate for an interrupted time series design due to the abbreviated time over which data is captured<br><br>Not appropriate for very low transmission settings (unless using PCR) or very heterogeneous transmission settings |
| | | Malaria Incidence | Number of confirmed cases / population size / unit time | Number of new cases per specific population per unit time. Often expressed as cases / 1000 population / year | Routine health facility data | Generally more appropriate for impact evaluation, but data quality validation is critical;<br><br>Analysis requires incorporation of a 30-day lag |
| | Economic | Incremental Cost-Effectiveness Ratio | Added cost of intervention / Added health benefit | Expressed as cost per DALY or case averted. Takes the total incremental cost of larviciding and divides it by the incremental benefit in terms of malaria cases prevented. | Cost data, routine health facility data | Calculation can be simplified by assuming the standard-of-care costs are similar in control and intervention arms (or before / after an intervention in the case of ITS). In this case, only the cost of larviciding needs to be quantified.<br><br>Case incidence needs to be quantified in both the intervention arm and the control arm (or before / after the intervention) to estimate the denominator.<br><br>Not compatible with a prevalence effectiveness metric |

## Table 8 continued: Key Indicators for Larviciding Programs and Measurement Methods

| Evaluation type | Category | Indicator | Calculation | Description / Relevance | Measurement Method(s) | Key Considerations |
|---|---|---|---|---|---|---|
| Process | Coverage | Coverage by habitat | Number of habitats treated / number of habitats targeted | Quantifies the proportion of targeted habitats that are treated with larvicide, and important indicator of team operational performance and potential impact of the intervention | Data from daily larviciding operator activities | Easier to collect than surface area, but could skew coverage estimates because not all habitats are similarly productive. Coverage changes quickly due to ephemerality of habitats and residual efficacy of product, so coverage is a "moving" indicator |
| | | Coverage by surface area | Surface area of habitats treated / surface area of habitats targeted | Quantifies the proportion of targeted habitat surface area that is treated with larvicide. | Data from daily larviciding operator activities | Programs should aim to collect surface area data if feasible because it can provide an additional useful metric. Coverage changes quickly due to ephemerality of habitats and residual efficacy of product, so coverage is a "moving" indicator |
| | Operational Performance | Larvicide Dosage Accuracy | Amount of larvicide used / surface area treated / target dose | Quantifies whether the amount of insecticide used by an operator in a day is appropriate for the surface area that they have treated. Expressed as a proportion of the target dose suggested by the manufacturer (or targeted by the program if different) | Data from daily larviciding operator activities | Programs would benefit by defining a threshold above or below which action is taken (e.g. 100 ± 10%) and what those actions should be.

This indicator can then be calculated at the larviciding operator level (indicating whether a team member is using the correct amount of insecticide) or aggregated to higher geographic levels (e.g. the proportion of habitats in a given area that received the correct dose). |

**Table 8** continued: **Key Indicators for Larviciding Programs and Measurement Methods**

| Evaluation type | Category | Indicator | Calculation | Description / Relevance | Measurement Method(s) | Key Considerations |
|---|---|---|---|---|---|---|
| Process continued | Operational Performance continued | Drone Flight Path Adherence | Indicators are usually automatically calculated by software. Programs should consult with drone manufacturer for support with interpretation. | | | |
| | | Treatment Success Rate | Number of habitats treated / number of habitats assigned | An indicator of larvicide operator efficiency. If an operator is not treating their assigned habitats, it may indicate problems with access, stock, or performance, and should be followed up. | Data from daily larviciding operator activities | Programs would benefit by defining a threshold below which action is taken (e.g. <90%) and what those actions should be. |
| | | Mapping Completeness | | An indicator of how well the habitats in an area have been identified and mapped. Proper mapping is essential for effective larvicide operations | Data from quality control checks | This data should be collected by a supervisor or dedicated quality control team. Can be regularly completed on a random sample of geographical locations in a given intervention area. |
| | | Larval Density | Average number of late stage L3 / L4 larvae per dip per habitat | Direct measure of larviciding effect on immature mosquito stages. | Larval surveys (dipping) | This data should be collected by a supervisor or dedicated quality control team. Can be regularly completed on a random sample of geographical locations in a given intervention area. Relevant for fast-acting larvicides (regardless of length of residual activity) |

**Table 8** continued: **Key Indicators for Larviciding Programs and Measurement Methods**

| Evaluation type | Category | Indicator | Calculation | Description / Relevance | Measurement Method(s) | Key Considerations |
|---|---|---|---|---|---|---|
| Process continued | Operational Performance continued | Pupal Density | Average number of pupae per dip per habitat | Direct measure of larviciding effect on immature mosquito stages. | Pupal surveys (dipping) | This data should be collected by a supervisor or dedicated quality control team. Can be regularly completed on a random sample of geographical locations in a given intervention area.<br><br>Relevant for fast-acting larvicides (regardless of length of residual activity) |
| | | Inhibition of Emergence (IE) | Number of immature stages that fail to emerge as adults / number of immature stages in the assay | Direct measure of larviciding effect on immature mosquito stages. Measures proportion of larvae / pupae prevented from transitioning to adults. | Dipping (for collection of mosquitoes) + Insectary observation | This data should be collected by a supervisor or dedicated quality control team. Can be regularly completed on a random sample of geographical locations in a given intervention area.<br><br>Relevant for Insect Growth Regulators (IGRs). Also an endpoint for resistance assays (see below) |
| | | Insecticide resistance | Number of larvae that are killed or prevented from emerging / number of larvae in the assay | Measures the proportion of larvae that are killed, or the proportion that are prevented from emerging, by exposure to the diagnostic concentration of larvicide. | Laboratory assays | Standard procedures for resistance testing are available from the WHO (21). Must include controls and correct for mortality % with Abbot's formula. |
| | Community engagement | Indicators vary widely depend-ing on scope of engagement. See table 7 for more information. | | | | |

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