Larviciding for malaria control in Africa_

A gap analysis and change management proposal

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June 2017

‘We have enough evidence, let’s get on with it’

72% of the experts/NMCP managers that took part in the online survey agree or strongly agree with this statement.

Image on front page adapted from Maheu-Giroux & De Castro, *Malar. J.* 2014, 13: 477.

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The views and opinions expressed in this report, apart from the quotes and responses resulting from the two online survey questionnaires, are those of the author and do not necessarily reflect the official policy or position of IVCC. Assumptions and assertions made within the analyses are not necessarily reflective of the position of IVCC, its staff, or its affiliated entities.

Acknowledgements

My appreciation goes out to Dr. Silas Majambere (IVCC) for his support, advice, and critical review of earlier versions of this report. I also thank Ingeborg van Schayk (MalariaWorld) for her assistance and support in setting up the online questionnaires, as well as writing and editing Appendix 2 and 3. The IVCC is gratefully acknowledged for providing the funds to perform this study.

1. Executive summary

Vector control has played a prominent role in advancing malaria control in Africa over the past fifteen years. However, the tools at hand, notably LLINs and IRS, are insufficient to drive transmission to zero. Moreover, these tools suffer from insecticide resistance, behavioural avoidance and outdoor biting mosquito populations, which therefore demands additional and/or novel vector control strategies. Larval source management (LSM), which includes larviciding, may be such a tool. Although larviciding is a common mosquito control approach in many parts of the world and has historically played an important role in elimination campaigns in countries now free of malaria, it is advancing only slowly in Africa.

The goal of this short-term consultancy was to review the factors that are hindering the adoption and wide-scale implementation of larviciding for malaria control in Africa. More specifically, the aims were a) to identify the factors that either positively or negatively influence the scaling up of larviciding, and b) to suggest options to capitalise on or address these. A limited literature review was undertaken as part of a STEEP analysis, two online questionnaires involving experts in the area of LSM/larviciding (representing researchers, donors, industry representatives, etc.) as well as the broader scientific community engaged in malaria research and control were conducted, and a Porter's five forces and gap analysis were undertaken. The outcome of these analyses formed the basis for a change management proposal based on Kotter's 8-step model of change.

The changing epidemiology of malaria in many parts of Africa, due to large-scale implementation of LLINs and IRS make the case for larviciding especially strong now that it has been observed that lower numbers of malaria cases and deaths result in reduced adoption and use of existing strategies like LLINs. New technologies are coming along that include aerial application, long-lasting formulations of biological control agents, and the potential of these larvicides to curb insecticide resistance. On the financial side, more information from pilot campaigns is becoming available, showing that even in rural areas and under a wide variety of transmission settings larviciding can be cost-effective. Perhaps most important is the policy regarding larviciding and LSM in general, which both hinders and blurs wider adoption of the approach since it prevents stakeholders from embracing the approach and promotes 'fence sitting'.

Sixty-nine experts and NMCP managers received the online survey, and their response rate was 33.3% (n=23). Out of the larger MalariaWorld and VCWG communities a 3% response rate was observed (n=248). There was strong agreement that malaria elimination in Africa requires new vector control tools and that larviciding should play a (significant) role in this, given the historical evidence that this tool is instrumental, if not mandatory, if elimination is the goal. The vast majority agreed that some form of larviciding in an area-wide fashion is needed to accomplish malaria elimination. The two most frequently mentioned reasons why larviciding has not (yet) been adopted on a large scale and in a variety of settings were cost and lack of political will/ignorance of policy makers. Lack of funding and evidence were also mentioned.

Although often debated, there is generally support for the notion that the historical campaigns that were conducted in Brazil (against the African vector *An. arabiensis*), the campaign in Egypt, and the elimination of malaria from Palestine, provide sufficient evidence that larviciding can play a major role in malaria elimination campaigns. With regards to WHO's triple-F strategy (the recommendation for adopting LSM in areas where mosquito habitats are few, fixed and findable), half the respondents back this policy, the other half not. Clearly there is scope for further policy development. In order to boost the approach, respondents pointed at governments to take the lead, and that they should be responsible for staging campaigns through community engagement. When asked to identify the major hurdles in moving forward operational complexity, restricted options for application, and the need for more evidence in a variety of settings were mentioned. However, two-thirds of the experts considered a WHO policy change as a critical first step.

The gap analysis identified a series of steps that can be taken to bridge the discrepancies currently present between the status quo and desirable state(s). This bridging effort should be driven by a sense of urgency, which, given the problems with malaria vector control today, should not be too difficult. It is proposed to establish a strong guiding coalition, consisting of a group of experts that represent the variety of stakeholders in this endeavour, augmented by representatives of all African NMCPs. This force is charged with the development of a strong vision and strategy derived from it, and will be playing an instrumental role in brokering knowledge in support of evidence building that is still required.

Ultimately it will be essential to demonstrate the true impact of larviciding through staging a range of trials ('Garki 2.0' pilot projects) across a variety of settings similar to the large-scale trials that were staged in the mid-1990 with bednets and should be monitored and evaluated accordingly. Only when larviciding in Africa is taken out of the realm of small-scale experimentation and is receiving the same cloud that planned MDA and vaccine trials enjoy will its true potential become unequivocally proven, accepted, and recognised as a key component of malaria eradication.

2. Abbreviations

Bs	*Bacillus sphaericus*
Bti	*Bacillus thuringiensis israelensis*
DDT	Dichloro-diphenyl-trichloroethane
GDP	Gross Domestic Product
IGR	Insect Growth Regulator
IRS	Indoor Residual Spraying
IVM	Integrated Vector Management
IVCC	Innovative Vector Control Consortium
LLIN	Long-Lasting Insecticide-treated Net
LSM	Larval Source Management
M&E	Monitoring & Evaluation
MDA	Mass Drug Administration
MDG	Millennium Development Goal
NMCP	National Malaria Control Programme
PAMCA	Pan African Mosquito Control Association
PMI	US President's Malaria Initiative
RCT	Randomised Controlled Trial
SSA	Sub-Sahara Africa
ToR	Terms of Reference
VCAG	Vector Control Advisory Group
VCWG	Vector Control Working Group
WHO	World Health Organization
WHOPES	WHO Pesticide Evaluation Scheme
WHO/RBM	WHO Roll Back Malaria

3. Introduction

Virtually all countries that signed up for the Millennium Development Goals in 2000 have shown dramatic advances in reducing malaria morbidity and mortality (as part of MDG6) over the last sixteen years. Global malaria incidence has dropped by an estimated 37% and mortality by 58% [1]. Close to one billion insecticide-treated bednets were distributed in sub-Saharan Africa and have been pinpointed as the primary contributor (68% of the total gains) to the observed reduction in *Plasmodium falciparum* prevalence in children 2-10 years of age, which dropped from 33% to 16% between 2000 and 2015 [2]. Combined with indoor residual spraying (IRS), these two vector control interventions made up for 78% of the estimated 663 million malaria cases averted and more than 6 million lives saved since the turn of the Millennium. This dramatic and highly encouraging progress has, for the second time in history, fuelled the belief that global eradication of malaria is feasible, and maps to show how its distribution will shrink to zero by 2040 have been drawn up [3], backed by equally optimistic reports [4] and the recently established End Malaria Council [5].

Considering the fact that vector control has played such a prominent role in these successes, there are two criticial issues to consider with regards to its future role in eradication efforts. First, it is now widely accepted that the current two major tools for vector control, LLINs and IRS, both highly effective alone or in combination, will not reduce malaria incidence to zero in high transmission settings [6, 6a]. Second, insecticide resistance in the major African malaria vectors, in some countries against several classes of public health insecticides recommended by the World Health Organization, is already widespread and increasing in intensity [7,8]. Without novel public health insecticides [9] and/or strategies to manage insecticide resistance [10,11], it will be difficult to sustain the gains of the last decade [12]. Beyond new actives there is also a dire need for novel tools that can be integrated with current methods, or combined with alternative approaches like larval source management [13], as part of integrated vector management campaigns [14].

A landscape analysis of vector control products was drafted in 2015 [15], with a focus on products and approaches that could be available for field implementation within the next few years (before 2020). Although it was acknowledged that larval source management (LSM) played a major role in malaria vector control in the past, it was also seen as having been surpassed by IRS and later LLINs. The latter approach, in particular, was regarded as requiring much less technical expertise, time and effort than LSM. Another concern that was raised is the fact that breeding sites may often be wide-spread and difficult to locate. As a result, the report mentions that larviciding should only be considered in settings where larval habitats are 'few, fixed, and findable' (the triple-F strategy), and should only be considered as a supplment to IRS/LLINs [13].

The WHO manual for LSM [13] mentions another important reason why larviciding, and LSM in general, with a focus on immature aquatic stages of the mosquito, is less favourable in terms of curbing malaria transmission. Based on the historical Ross-Macdonald model [16] it is argued that the daily survival ('p') of adult female mosquitoes and their preference for human bloodfeeding (the 'a' in the equation) have a much higher impact on the basic reproductive number of malaria (R_0) than the density of female mosquitoes (the 'm' in the equation). Thus, targeting the adult (possibly infectious) vector has a much greater effect on malaria transmission than targeting larval stages; reducing the lifespan of an afrotropical malaria mosquito by 50% can result in reduction of the transmission potential by 99% [17]. Consequently, malaria vector control in the last half century has largely shifted towards IRS, and more recently LLINs, since these tools directly affect daily adult female survival.

There are additional reasons why LSM, and in particular larviciding, has not reached prominence in the malaria vector control field, and epidemiological and operational/logistical justifications to move away from it are most frequently heard (Box 1).

Box 1. ***Factors frequently cited against the use of Larval Source Management (including larviciding).***

- Epidemiological arguments
    - Malaria transmission is more driven by the daily survival rate of the adult female mosquito (p) because she needs to survive the duration of the extrinsic incubation period (n). Since this is factored in the Ross-Macdonald model as p^n even a modest lowering of p can have a major impact on the transmission intensity.
    - Host preference (a) is squared in the Ro equation (a mosquito needs to bite people at least twice in order to transmit parasites), and protection against bites thus lowers the proportion of successful feeds on humans and thus transmission intensity.

- Operational/logistics arguments
    - The 'effort per capita paradox': Areas with lots of people in small areas (urban settings) are more suitable for LSM than extended areas with few inhabitants (rural settings).
    - The 'triple F' dilemma: LSM is only suitable in settings where breeding habitats are 'few, fixed, and findable'.
    - Breeding sites are too widely scattered and difficult to reach.
    - LSM requires extensive logistic planning and training of operational staff.

- Cost arguments
    - Too many breeding sites need to be treated/modified, especially in rural areas, making the effort too costly.
    - The residual effect of larvicides is too short, requiring frequent application, which increases operational costs.

WHO also recommended that resources for core interventions (LLINs and IRS) should not be diverted for larviciding in such settings [13, 18].

The interim position statement and the operational manual based on it resulted in relatively few African NMCPs adopting larviciding or other components of LSM in their malaria control strategy. Clearly, the recommendations were far from conducive for NMCPs to embark on experimental evaluations in various ecological settings. Funding for LSM/larviciding, as a consequence of the WHO documents, was not coming forward from large funding organisations, which also hindered progress. By 2012, no decent review of the various trials that incorporated larviciding/LSM was available (although it was published, based on 13 trials, in 2013, see [19]). The authors of that Cochrane review concluded that in Africa and Asia reductions of up to 75% in malaria incidence and up to 90% reduction in malaria prevalence may be achieved in appropriate settings. LSM is another policy option, alongside LLINs and IRS, for reducing malaria morbidity in both urban and rural areas where a sufficient proportion of larval habitats can be targeted. They recommended further research to evaluate whether LSM would be appropriate or feasible in parts of rural Africa where larval habitats are more extensive.

In spite of difficulties in operationalizing LSM in Africa, there has been growing and renewed interest in LSM/larviciding since the turn of the millennium. Based on historical campaigns that were successfully executed over sometimes extremely large areas, notably the eradication of the African malaria vector *Anopheles arabiensis* from Brazil and the near-elimination of the yellow fever mosquito *Aedes aegypti* from the whole of South America by 1962 fueled this new enthusiasm [20-22]. New formulations of biological larvicides became available, that were initially piloted on a small scale [23, 24] and subsequently in larger trials in rural [25,26] and urban settings [27,28], with mixed [29] but generally encouraging outcomes. Even prior to publication of the Cochrane review on LSM, in 2011, the notion was challenged that LSM cannot be successfully used for malaria control in

African transmission settings by highlighting historical and recent successes, discussing its potential in an integrated vector management approach working towards malaria elimination and critically reviewing the most common arguments that are used against the adoption of LSM [30]. A cost analysis of LSM proved favourable in comparison with IRS or LLINs in settings with moderate and focal malaria transmission and where the human population density relative to the density of aquatic habitats is high, and breeding sites can easily be defined, located, and treated [31]. Yet, studies with conflicting outcomes persisted – trials in Kenya, in which the integrated use of larviciding and LLINs was evaluated, yielded both positive [32] and (at best) modest [33] outcomes.

The Larval Source Management (LSM) work stream (WHO/RBM) works to update the evidence base and protocols, presentations and meeting reports of its annual gatherings are available online [34]. It also aims to assess and develop the local capacity (people and infrastructure) to help national programmes identify where and how investments in LSM could contribute to malaria control through integration with other interventions. During its most recent (7^{th}) meeting in February 2017, it was reported that globally, at present, nearly 60 countries implement some form of larval control [35], and that 24 out of 46 African nations apparently do so on a smaller or larger scale [36]. LSM therefore appears to be an increasing trend, and a scoping exercise to determine LSM implementation and financing strategies in five African countries (Ghana, Nigeria, South Sudan, Uganda and Tanzania (Zanzibar)) is currently being undertaken [37].

Although larviciding is an old tool for mosquito control and has played a prominent role in malaria elimination efforts in many countries (USA, Europe, Australia, etc.), its wide-scale adoption for malaria control (and elimination) in Africa is only starting. Given the complexity and multitude of factors that may influence, promote or hamper the wide-scale use of larviciding it should not be surprising that many stakeholders currently are fence sitters at best, often sceptical, but at times straightforward dismissive (Box 2). These factors include technological factors (application technology, duration of efficacy, locating habitats and access), delivery system issues (capacity), economic reasons (e.g. price, cost-effectiveness, affordability, financing options), evidence (strength and influence) and policy matters (WHO position statement, policy champion).

If larviciding is to play a more prominent role in sub-Saharan Africa in the coming decades, and if it is to become a (significant) contributing factor to the ultimate goal of malaria elimination [39], then managing the broad variety of (conflicting) stakeholder interests (Box 2) becomes essential. In order to accomplish this, an inventory of views and opinions (from an expert panel and the broader global professional malaria community) was made, as well as a STEEP analysis in which the most important Sociological, Technological, Environmental, Economical and Political/Policy factors are viewed from different perspectives. The feedback from the experts and malaria community, in combination with the STEEP analysis formed the basis for a GAP analysis (from 'where we are' to 'where we want to be' and 'what steps do we need to make to get there'). In turn, the outcome of the GAP analysis formed the basis for implementation of Kotter's 8-step model of change.

Box 2. ***Examples of conflicting stakeholder interests***

- **Government/MoH:** Will not adopt LSM without guidance and policy
- **(Implementation) Funder:** Will not fund LSM without recommendation from policy maker
- **Policy maker:** Will not draft policy until sufficient evidence has been generated by researcher
- **Donors:** Needs more evidence (from RCTs) from researchers before releasing funds
- **Researchers**: Cannot generate more evidence without support from the funder
- **Industry:** Will not develop new products without significant market potential
- **Industry/business**: Promote pragmatism and opportunism, trial and error, learning factory
- **Policy makers**: Promote conservatism, know-it-all before proceeding, risk averse
- **Researcher**: Wants publications in high-impact journals
- **Industry**: Wants profit from product sales
- **Government**: Wants to maximise public health impact at the lowest cost possible

4. Goal and objectives

The goal of this short-term consultancy was to review the factors that are hindering the adoption and wide-scale implementation of larviciding for malaria control in Africa.

More specifically, the aims were a) to identify the factors that either positively or negatively influence the scaling up of larviciding, and b) to suggest options to capitalise on or address these. For an outline of the original Terms of Reference, see Appendix 1.

5. Methodology

An important restriction in this report is the fact that it deals with larviciding only and not Larval Source Management (LSM) of which larviciding is merely one of the four components (that also include habitat modification, habitat manipulation, and biological control (e.g. fish)[40]. In this report, larviciding will be viewed as: *Regular application of biological or chemical insecticides to water bodies*, which is how it is defined in the WHO manual on Larval Source Management [13].

Two sources of information were used in this study. Secondary data were obtained through mining available scientific articles on larval control in Africa. Secondly, two surveys to gather primary data were conducted, one amongst a small group of experts (representing a variety of stakeholders in this field) and managers of African national malaria control programmes (NMCPs) that served as key informants for a larger survey that was emailed to a much larger scientific community engaged in malaria (vector) research and control.

5.1. Literature review and search strategy

The following search strings were used in PubMed:

1. larviciding[All Fields] AND ("malaria"[MeSH Terms] OR "Africa"[All Fields]), which yielded 87 articles;
2. larviciding[All Fields] AND ("malaria"[MeSH Terms] OR "malaria"[All Fields]), which yielded 80 articles;

3. (larviciding[All Fields] AND ("malaria"[MeSH Terms] OR "malaria"[All Fields])) AND Review[ptyp], which yielded 6 articles;

Within the timeframe of this study it was not possible to undertake an in-depth review of all of the above articles. Considering that the following documents collate a substantial number of scientific articles and evaluations until 2013, i.e.,

- World Health Organization (2013). Larval Source Management: A Supplementary Measure for Malaria Vector Control. An Operational Manual. Geneva, Switzerland: World Health Organization.
- Tusting LS, Thwing J, Sinclair D, Fillinger U, Gimnig J, Bonner KE, Bottomley C, Lindsay SW (2013). Mosquito larval source management for controlling malaria. *Cochrane Database of Systematic Reviews*, Issue 8. Art. No.: CD008923. DOI: 10.1002/14651858.CD008923.pub2.

the focus was therefore on the following search in Pubmed, which yielded 25 (21 after review were suitable for inclusion) articles published between 2013 and today:

4. larviciding[All Fields] AND ("malaria"[MeSH Terms] OR "Africa"[All Fields]) AND ("2013/01/01"[PDAT] : "2017/01/15"[PDAT])

5.2. STEEP analysis

The articles that matched these search criteria were reviewed in order to identify critical issues belonging to five main categories: 1. Sociological/societal, 2. Technological/operational, 3. Environmental, 4. Economic, and 5. Political/policy. This STEEP analysis is a tool commonly used to evaluate different external factors and trends which impact an organization, project, or activity and it is essential to consider these external forces before making decisions and gauging the outcome of new developments. The issues identified from the literature published over the last four years also informed the drafting of the questions for the questionnaires.

5.3. Questionnaire - Key informants and NMCP managers

Given the limited timeframe for this consultancy it was decided to select a small group of representatives from selected backgrounds/organizations that are engaged in larval, vector, or malaria control in general, notably academia/research organisations, industry, funding bodies, or government/policy organisations. Twenty-three (23) experts and fifty-four (54) African NMCP managers[1] were selected and contacted by email, with a link to the online semi-structured questionnaire. Names and contact details of these 77 persons invited to participate in the survey are known by IVCC. The online survey was developed using the SurveyMonkey application (www.surveymonkey.com) and contained 53 questions in 21 categories. Twenty (20) of these open questions provided the option for respondents to add remarks/comments; thirty-three questions were closed. The survey questions were presented to, and discussed with, IVCC and agreed upon prior to distribution and are added as Appendix 2. The survey was activated on 5 March 2017 and closed on 23 March 2017. A week after the original invitation was mailed, a reminder email was sent to those that had not yet responded.

[1] Names and email addresses of NMCP managers were provided by IVCC (Dr. Silas Majambere).

[2] Weighted average = $(w_1n_1 + w_2n_2 + \ldots w_xw_x)$/total, whereby the number of most preferred answer (w_1) receives

5.4. Questionnaire – MalariaWorld and VCWG communities

Based on the feedback from experts/NMCP managers a selection of eleven (11) closed questions (in English) was distributed to the MalariaWorld community (more than 9200 subscribers in >140 countries), as well as the VCWG mailing list (1462 vector control specialists). MalariaWorld and VCWG subscribers received a special email with invitation to participate and a link to connect to the survey (again using the SurveyMonkey application) online. At the end of the survey provision was made for respondents to add general remarks or comments. The survey questions are added as Appendix 3. The survey was activated on 2 April 2017 and closed on 10 April 2017.

5.5. Porter's five-forces analysis

In order to evaluate the position of LSM, and in particular larviciding, within the broader field of malaria (vector) control, a Porter's five-forces analysis can be performed. This analysis studies the issues within 'the field', or 'rivalry within the sector' first and then the influence of new developments that may impact on the potential of LSM/larviciding, or the power and impact of new players in the field. Equally important is the position, influence and power of suppliers and the consumers, in this case suppliers of larvicides and spray equipment and additional technology, but also suppliers in terms of funding. Consumers are the 'buyers' of the approach (e.g. government agencies or other executing parties or 'end-users' including communities living in areas where larviciding is adopted and implemented). All of these forces will influence the potential and future implementation of LSM/larviciding. For the purpose of this report, the five forces are grouped according to the selected literature and augmented with additional (published) developments in the field of malaria control and elimination efforts.

5.6. Gap analysis framework

Based on the STEEP analysis, feedback from the questionnaires, and Porter's five-forces analysis a Gap analysis framework was drawn. A gap analysis framework starts with defining a desirable future state of a certain aspect of the topic under study, subsequently describes the current status of this aspect, on the basis of which the 'gap' can be identified. This gap is then matched with the views of the experts/NMCP managers as well as the feedback from the broader vector control community in order to arrive at actionable propositions that will help to bridge the identified gaps.

5.7. Recommendations: Implementing the change

Based on the Gap analysis framework and all the identified action points, a framework can be drafted to implement the change, in this case by using Kotter's 8-step model of change. Kotter's change model is one of the most widely used models in organizational change. Like any other model it has certain strengths but also weaknesses. It was chosen here because of its linearity, steps that can be clearly defined, is easy to follow and understand, and functions best in a culture of classical hierarchies, which fits the topic of LSM/larviciding well. Ultimately, the model helps to define the actions to 'bridge the gaps', and bring LSM/larviciding more to the forefront so that it can play a prominent role in malaria elimination efforts across Africa in the years to come.

6. Results

6.1. STEEP analysis

6.1.1. General

With the current success of ITN/LLIN and IRS programmes in many parts of Africa, more and more areas that previously experienced intense and often perennial transmission now show characteristics of low, seasonal and focal malaria transmission which offers great opportunities for the implementation of LSM, and larviciding in particular [45, Box 3]. Reduced transmission intensity has been noted as an important factor why LSM/larviciding may become increasingly important in malaria vector control.

Moreover, considering the problems associated with massive up-scaling of LLINs, notably a shift in vector species abundance and vector behaviour, the need for outdoor vector control methods will become increasingly important. In many parts of East Africa, for instance, the primary malaria vectors *Anopheles gambiae s.s.* and *An. funestus*, which are both strongly anthropophilic and endophagic, have been dramatically reduced in density due to wide-scale implementation of nets and IRS, making the outdoor and more opportunistic feeder *An. arabiensis* the vector of prime importance at present. The more opportunistic feeding behaviour of this vector makes it harder to control since part of its bloodmeals are taken from animals (e.g. cattle) through which it evades exposure to indoor insecticide-treated surfaces (nets or walls)[41].

Beyond the changes in vector feeding behaviour there are also major concerns related to resistance of malaria vectors to synthetic pyrethroids and the four classes of chemicals used for IRS [61]. There is also a pressing need to include interventions that can tackle residual malaria transmission in the present malaria control paradigm and to develop viable insecticide resistance management strategies to help malaria control and elimination efforts in sub-Saharan Africa [41]. Maheu-Giroux and Castro (2013) summarise the above as follows: "With important projected increases in urban population in sub-Saharan Africa, mosquitoes' behavioural adaptation to current control strategies, and the already recorded emergence of resistance to pyrethroid insecticides, larval source management, and larviciding in particular, should be given careful consideration by managers of malaria control programs" [52].

Box 3. ***Recently published general views regarding LSM/larviciding***

- The **changing epidemiology** of malaria in many parts of Africa, due to large-scale implementation of nets and IRS makes the case for LSM/larviciding stronger.
- Observed **changes in vector behaviour** require outdoor, area-wide control methods that will also target partially zoophilic vectors that have proportionally become more prominent in malaria transmission.
- **Resistance to insecticides** used in LLINs and for IRS demands additional tools to target residual transmission.
- Examples of **successful implementation** of LSM/larviciding exist for both urban and rural settings in several African countries.
- There is a strong push in the scientific community for **biological control using Bti**.

Considering the fact that 24 African countries are already, to a smaller or larger extent, implementing LSM/larviciding, and given the reported successes of well-established multi-year programmes in urban settings (Khartoum, North Sudan and Dar es Salaam, Tanzania) as well as rural settings (127 villages in western Burkina Faso) it is somewhat surprising that wider adoption of the approach to reach the same status as LLINs and IRS has not been forthcoming. The success of the programme in Burkina Faso is especially interesting in that regard, since it argues against the current policy that LSM/larviciding should only be implemented in areas where breeding sites are few, fixed, and findable. Lead author Peter Dambach of a 2016 article sums it up as follows: "Larvicide-based LSM is an additional, complementary tool for malaria control programmes that so far did not receive the attention it deserves for designing national and international policies. Particularly, in combination with LLINs and IRS it proved to be a highly effective malaria vector control measure. For selected environments the use of remote sensing derived risk maps might be a promising approach to reduce the number of treated water bodies while, at the same time, keeping programme costs at reasonably low levels. Although today's WHO recommendations promote the use of LSM mainly for urban areas with high population densities with the underlying idea of obtaining reduced costs per person, rural areas should not be considered a priori as ineligible for spraying interventions. Given the continuously adapting nature of malaria vector mosquitoes to insecticides, we make a case to shift more attention to hereto unaffected control strategies such as Bti based LSM" [46].

A striking observation when reading the published literature of the past few years is the fact that strong arguments are made against the use of chemical control methods leading to strong promotion of biological control. In contrast, the recurring argument against the use of biologicals is their apparent short residual efficacy. Nevertheless it can be argued that the vector control field is 'blurred' by the notion that residual efficacy needs to be 6 months (a DDT legacy?). Cost-effective implementation models that require more frequent application of biologicals should be considered and apparently are surfacing. However, even chemicals now used in IRS (like the carbamate bendiocarb) have a much shorter residual efficacy than the 'golden standard' of 6 months. Most recent studies have focused on the use of *Bacillus thuringiensis israelensis* (or *Bti*), and formulations with much longer residual efficacy are being developed and have recently been tested successfully (see section 6.1.3).

6.1.2. Societal/Sociological issues

Larviciding as an add-on tool in integrated vector management (IVM) campaigns may have clear advantages over house-based interventions. With dropping morbidity and mortality rates due to the use of LLINs/IRS there may be increasing resistance to using these latter tools since community perception may be that malaria is no longer a serious problem. In parts of Africa resistance of household owners to IRS is increasing due to stains or smell of the chemicals sprayed indoors, or beliefs of negative impact of the insecticide on human health. To some degree this also applies to resistance to using bednets. Effective area-wide vector control using larvicides will further reduce vector populations and likely decrease willingness to sleep under bednets or have houses sprayed. A study by Maheu-Giroux and Castro in Tanzania showed that the probability that individuals targeted by larviciding [in Dar es salaam] had used a bednet was reduced by 5% as compared to those in non-intervention areas and the magnitude of this effect increased with time. Larviciding also led to a decline in household heads' knowledge of malaria symptoms but no evidence of effect on knowledge of malaria transmission was found [52]. Thus the reduction in the prevalence of malaria infection, from 20.8% in 2004 to 1.7% in 2008, following larval control could potentially change the individual perception of malaria risk. In this case from Tanzania, the disease was not perceived as a threat to health anymore, leading to varied behaviour changes, including reduced adoption of personal protective measures, such as bednet use [51,52].

A great advantage of larvicides based on the mosquito-specific toxins produced by *Bacillus sphaericus* (Bs) and *Bacillus thuringiensis israelensis* (Bti), which makes them promising tools for larval control is their selective nature and non-toxic properties, which renders these ideal for use in community settings. While essentially non-toxic in their natural state, once ingested and digested by immature mosquitoes, these toxins selectively kill the larvae of vulnerable Diptera [46]. Bti is therefore unlikely to pose any hazard to humans, other vertebrates and non-target invertebrates, provided that it is free from non-Bt microorganisms and biologically active products other than the insecticidal crystal proteins [48].

Finally, a recent study conducted in east-central Tanzania by Leonard Mboera and colleagues indicated that rural community members were likely to be receptive to larviciding for malaria control, and more so following adequate community sensitization. Members of the households were willing to contribute across a range of possible quarterly payment levels to support a larviciding programme in their villages. The results of that study indicated a receptive environment for future efforts directed at larviciding for malaria control in a rural Tanzanian setting [55].

Box 4. ***Societal/sociological issues regarding LSM/larviciding***

- The **changing epidemiology** of malaria in many parts of Africa, due to large-scale implementation of nets and IRS make the case for LSM/larviciding especially strong now that it has been observed that behaviour change leads to reduced adoption, use, and knowledge about existing strategies (like LLINs and IRS).
- Biological larvicides (Bti and Bs) have a great advantage of being practically **non-toxic to humans**, which renders these extremely suitable for community use.
- Studies (in Tanzania) have shown willingness to pay in communities for larval control activities in their surroundings but required adequate sensitization efforts.
- There is a strong push amongst scientists for **biological control using Bti**.

6.1.3. Technological/Operational issues

Although integrated vector management (IVM), targeting both larval and adult mosquitoes has received a lot of attention recently because of its potential in the control and elimination of malaria [56], there are various technical and operational issues that may hinder its wider adoption. Larviciding can be particularly effective in urban areas where transmission is focal and accessibility to *Anopheles* breeding habitats is generally easier than in rural settings, but this also highlights one of the key hurdles for a successful larviciding programme: the ability to identify, locate and have access to all potential breeding sites in targeted areas [51]. Access (or rather the lack thereof) to breeding sites may leave certain pockets of larval breeding unaffected by spraying efforts that may influence the outcome of a campaign negatively. In The Gambia, for instance, a larviciding trial did not result in a reduction in clinical malaria or anemia; the reported reason for this was lack of access to breeding habitats when using ground application of larvicides, in this case in riverine areas with extensive flooding [26]. Accessibility as well as effective terrain reconnaissance therefore remain critical in order to achieve high enough coverage of breeding habitat to ascertain impact on malaria transmission. Recently, new technologies have become available that can aid reconnaissance, notably the use of drones that were deployed successfully for malaria vector habitat surveillance in Zanzibar [62]. Efforts to use drones not only for surveillance but also as unmanned aircraft for larvicide application are under development in Kenya (G. Welter and R. Mukabana, *pers. comm.*). In future it may even be possible to use drones as independently operating larvicide delivery applicators that are capable of detecting standing surface water (on the basis of spectral reflectance using optical sensory equipment), determine the size of the total water surface, calculate the required dose of insecticide, and apply it.

Another key concern often expressed when discussing the potential of larviciding is the short residual activity larvicides generally have. Most formulations of Bti show a strong lethal effect on larval populations that may last for a period 1-2 weeks [56], and result in substantial reductions in adult vector densities [46]. So even though most commercially available chemical larvicides and microbials are highly effective in controlling the major African malaria vectors, a major limitation is their short activity under most environmental conditions, which frequently necessitates weekly reapplication [54]. Recently, however, Afrane and colleagues successfully evaluated a slow-release briquet formulation of Bti. In semi-natural conditions, the FourStar™ briquets 180-days formulation completely inhibited mosquito pupal production in the first 3 months, and then reduced pupal productivity by 87-98% (P < 0.001) 4-6 months after application. In natural habitats, during the first 2 months no pupae were detected from any of the treated habitats in highland sites, and Anopheles spp. pupal density was reduced by 60-90% in the next 3-5 months (P < 0.001). In the lowland site, pupal productivity reduction was 100% in the first 3 months, and 75-90% in the next 4-5 months (P < 0.001). The randomized cluster trial found that the application of the briquets formulation reduced mean densities of indoor-biting mosquitoes by 76-82% (P < 0.001) and by 67-75% (P < 0.001) for outdoor-biting mosquitoes [41]. With increasing interest in larviciding it is likely that more long-lasting formulations will become available.

On the other hand there are also clear advantages of the approach. Perhaps the most striking advantage is the fact that, in spite of its large-scale and long-term use in places, that no resistance has so far been observed against Bti. Evasion of contact with such insecticide by larvae is impossible when treating water surfaces and the fact that larvae are concentrated, immobile and accessible make larval control with Bti particularly attractive. It is impossible for larval stages of vectors to change their behaviour and as such avoid contact with Bti [46,55]. However, whether or not this will affect the future effectiveness of Bti remains unknown at this stage.

Regarding operational issues, it is reported that larviciding requires professionals with special skills. A large-scale LSM programme requires the employment of different types of personnel: For project management, risk map creation, and entomological training highly trained professionals are required, while for spraying activities laypersons from the villages can be hired and trained within a short time. Strong local partnership, meticulous planning with the possibility of ad-hoc adaption of project components and a reliable source of funding also turned out to be crucial factors to successfully accomplish such an LSM project [46]. The urban programme from Dar es Salaam reported the following lessons regarding the implementation of larval control: (i) breeding habitats can, and should, be mapped at high resolution using low-cost technology, (ii) locally relevant entomological information should be collected to inform operational activities, (iii) monitoring and evaluation systems should be implemented to ensure effective and appropriate delivery and fine-tuning of interventions, and (iv) community involvement and sensitization can be beneficial to programmatic activities [51,52].

6.1.4. Economic issues

There have been only a limited number of studies in which the per capita costs of larviciding were calculated and published. In Burkina Faso, the per capita costs for larval source management interventions with Bti were roughly a third of the annual per capita expenditures for anti-malarial drugs and those for LLINs, which were US$ 3.80 and 3.00, respectively. The average LSM costs are comparable to those of IRS and LLINs for sub-Saharan Africa, even in areas where the WHO criteria are not fulfilled [31]. The authors argue that in such a setting LSM based on Bti spraying is within the range of affordable anti-malarial strategies and, consequently, should deserve more attention in practice [46]. There are limitations to the economically efficient application of LSM [based on Bti] for areas with a high annual malaria transmission and vast areas covered by surface water. However, in the light of recent control efforts with LLINs, more areas show reduced malaria transmission during an increased number of months. This would make the additional implementation of larvicide-based LSM economically suitable even in previously unsuitable regions, provided it is part of integrated malaria control, i.e. applied together with medical treatment, LLINs and IRS [46]. Combined, the different studies indicate a cost per capita of ca. 1.5 US$ per annum [31,46,63].

The cost-effectiveness of the approach is, however, not favourable in all settings. In urban Tanzania the cost-effectiveness of larviciding was shown to be highly dependent on the assumed baseline malaria incidence [53]. The latter authors are somewhat contradictory: They support the use of larviciding as a cost-effective intervention in urban areas and therefore encourage managers of national malaria control programme to consider this intervention as part of an IVM approach. And go even one step further by arguing that given Tanzania's per capita GDP of $599 USD (2012), larviciding could be considered very cost effective under a wide variety of transmission scenarios. At the same time they caution that with limited health budgets decision makers should still prioritize scaling-up LLINs and IRS in rural areas because larviciding interventions were shown to be more costly when the density of breeding habitats is high and/or human population density is low. Once coverage of these interventions would be satisfactory in highly endemic areas, larviciding could be part of an IVM approach for malaria control, if local conditions warranted its use [53]. Finally, they linked cost-effectiveness to malaria incidence and found that the approach is highly cost-effective in areas where incidence exceeds 110 per 1,000 per annum (above 40 infections per 1,000 to be deemed cost effective).

Larvicide and labour are the major costs in large-scale larval control programmes and these could be substantially reduced if re-application intervals could be reduced without jeopardizing the impact of the intervention [54]. Longer effective duration would reduce the frequency of habitat re-treatment and thus help to reduce operational costs [41]. There is a desperate need for a new formula of Bti that lasts for a whole transmission season of three to four months and will not be washed away by heavy rain, to reduce the financial cost as well as labour required, and to make it appropriate for large-scale application [60].

It is noteworthy though that cost-effectiveness analyses are rather limited, both for urban and rural settings and it remains largely unknown which combinations of interventions (e.g. LLINs, IRS, LSM) are most cost-effective in different settings.

6.1.5. Environmental issues

The discovery of biological control agents in the 1970s resulted in great environmental health benefits when these were used in larviciding campaigns compared to the much more toxic substances that had been in use since the beginning of the 20th Century (e.g. Paris green). The biological larvicides *Bacillus thuringiensis israelensis* (Bti) and *Bacillus sphaericus* (Bs) allow for environmentally sound and specific killing of vector larvae [47,51,52,55,61]. Also some chemical larvicides, like pyriproxyfen or dimethylsiloxane, have been evaluated as safe, even for application in/on drinking water, and with minimal impacts on non-target aquatic insects and the environment (Mbare et al., 2013). It goes beyond the scope of this study to evaluate the environmental (dis)advantages of the various larvicides, but it can be ascertained that currently very safe products are available that will likely not face serious problems with resistance in (the near) future. For an overview of currently recommended larvicides, see the WHOPES website [64].

There are nevertheless some environmental issues that impact on the potential for larviciding as additional vector control tool. Dambach et al. [44] found that the potency of Bti formulations could decrease substantially in Burkina Faso where the intensity of sunlight as well as the water temperature is high. Environmental conditions influence the residual effect of larvicides. Heavy rainfall, for instance, may wash away larvicides and create new habitat; therefore, additional larvicide may need to be applied at an unplanned time after the rain [61]. Dilution of larvicides due to flooding or expansion of the volume/surface of breeding sites may therefore, especially for the chemical larvicides, cause rapid development of resistance. Size, depth, permanence, temperature, larval food availability and the presence of predators will all affect mosquito productivity of a given habitat and these parameters change over time. In turn, these will affect the choice of larvicide and mode and frequency of larvicide application [61].

6.1.6. Political/Policy issues

The official World Health Organization recommendation states that, specifically for larviciding, "further evidence is needed of the value of larviciding as a routine and large-scale operation in both urban and rural areas" (WHO 2012; Tusting et al., 2015). WHO's position statement also makes a comparison between the ratio of larval habitats to people in urban areas (low) and rural areas (high). Thirdly, it does not generally recommend larviciding in rural sub-Saharan Africa unless particular circumstances limit larval habitats, i.e. larviciding should be considered for malaria control (with or without other interventions) only in areas where the larval habitats are few, fixed and findable" (WHO 2012).

Box 5. ***Outstanding issues regarding LSM/larviciding***

- **Where:** In spatial terms, how should larviciding best be implemented? Can it be focal or should there be high coverage levels in order to be effective? Which (agro)ecosystems in combination with human activities are best suitable to adopt larviciding? Can it only work in places where breeding habitats are 'few, fixed, and findable? Can it only work cost-effectively in places where many people inhabit relatively small areas (urban environments)?
- **When:** Does it make sense to use larviciding during the rainy season when it is operationally difficult to keep coverage high? Should larviciding be a continuous operation or only be deployed during certain times of the year?
- **What:** What are the best choices regarding larvicides? Are the current formulations/products adequate and sufficient?
- **Who:** Should larviciding be executed like IRS campaigns? To what extent does the approach lend itself for community engagement? Who will/should pay?
- **Why:** What are the criteria to choose for LSM/larviciding as an add-on option besides already used strategies (LLINs/IRS)? What determines the choice for larviciding? Is larviciding the best option or should other vector control options be explored?
- **How:** Should larviciding only be used in combination with other vector control tools to be effective? Are there options to improve coverage by using application technology that move beyond ground application (e.g. drones)? Who should be the driver to move larviciding forward in malaria vector control?

These WHO recommendations affect policy-making in two important ways: First, there is accumulating evidence that larviciding can and should play a role, even in rural areas, even in places where larval habitats may not be few, fixed and findable. Lucy Tusting and colleagues [59] report of trials in rural Africa such as in Mali, Eritrea and Kenya that showed that malaria transmission was reduced with larviciding. They also found that, while the extent to which larval habitats are 'findable' may be important, larviciding may be effective where larval habitats are not necessarily few or fixed. They also caution against the urban-rural distinction since in some rural areas in Africa and elsewhere larval habitats may be equally limited in number, easily mapped, and accessed, as in more urban settings.

These findings contrast with the views expressed in current policy documents (like those from WHO). Moreover, the absence of specific knowledge and capacity hinders the formulation of evidence-based national policy elements to promote and support larval source management [55].

Clearly, the above review of recent published articles in terms of STEEP factors has shown that since the publication of the Cochrane review on LSM in 2013 much progress has been made and that larviciding is slowly gaining more interest across Africa. Nevertheless, the above also highlights remaining questions (Box 5) that combined provided input for the development of the questionnaire.

6.2. Questionnaires
6.2.1. Responses received

The invitation to participate in the online survey was sent out to 23 experts and 54 NMCP managers. Eight email addresses of NMCP managers bounced or were no longer in existence, which reduced the survey group to 69 persons). This group yielded an overall response of 23 (33.3%) of which 18 yielded fully completed questionnaires (i.e., 5 respondents did not fill out one or more questions). Only four respondents indicated that they are NMCP senior staff or manager based in Africa; one indicated to be based in the USA. The response from African NMCPs was therefore very low (3 out of 46, or 6.5%).

A total of 268 persons responded to the invitation received by email from MalariaWorld or the VCWG mailing list. The MalariaWorld population is 9200 persons in size and the VCWG mailing list has 1462 members, and although there will be substantial overlap between both databases, it may be assumed that the response rate was close to 3%.

For easy reference to the two questionnaires, in the text below reference is made to 'experts' whenever it concerned the questionnaire sent out to the smaller population of selected experts and NMCP managers, whereas reference is made to 'the community' whenever it concerned the second questionnaire distributed amongst the MalariaWorld/VCWG communities.

6.2.2. Should vector control in Africa include larviciding?

Since massive progress has been made in malaria vector control over the past 15 years, primarily with two house-based interventions (LLINs and IRS), respondents were asked if there is a need for additional vector control tools besides LLINs and IRS? The experts (100%) as well as the community (94%) were in strong support of adding additional vector control tools.

When the experts were asked to indicate what tools they see suitable to add to the existing arsenal within the next 5 years, they (21 responses) mostly (15) indicated LSM/larviciding, which may not be surprising given the topic of the questionnaire. Attractive Toxic Sugar Baits (ATSB) were the only additional option mentioned for indoor use; general house improvements to reduce indoor biting (screening, eave curtains and tubes) were also mentioned, besides spatial repellents. Considering the forthcoming new public health pesticides there is hope that real long-lasting IRS will become an option within a few years. Regarding efforts beyond the confines of the house, experts not only mentioned larviciding with the current biological control agents but also IGRs and monomolecular films. Interestingly, space spraying/fogging or outdoor residual ULV adulticiding was mentioned by several respondents as a strategy that has hardly received attention in the African context but may ultimately play a role in elimination efforts or focused outbreak management.

The importance of larviciding in malaria elimination campaigns was considered very high by both groups of respondents. None of the experts knew of a country that had succeeded in eliminating malaria *without* some form of larval source management; this was 93% for the community responses, where some mentioned countries where malaria has not been eliminated (yet), like Zambia, South Africa, Rwanda, Senegal, Zanzibar (UR of Tanzania) or Zimbabwe to have succeeded without LSM. Others mentioned countries that have eliminated malaria but did use LSM as part of its strategy (like the USA and Italy). In some countries, it was mentioned, LSM played only a minor or no role, notably Mauritius. Overwhelmingly though, respondents indicated that LSM has a critical role to play if malaria elimination is the goal (Box 6).

When asked if malaria elimination in SSA will require some form of area-wide vector control targeting larval stages 95% of the experts and 70% of the community were affirmative. In the latter group 22% indicated 'don't know'. One expert elaborated on this requirement as follows:

> *"Area-wide larviciding is needed to address large larval sources or aggregations of many small sources. Large sources such as rice fields and floodplains will remain foci of residual transmission if not addressed. Rapid and complete coverage of small sources, especially in village and urban settings can be assured with wide area treatment. Focal spraying by backpack application will always have its place, but can be limited by performance of individual spray personnel, habitat conditions and access to properties. Properly timed area-wide applications will strongly impact mosquito population development early in the rainy season when populations are in the log-phase of growth."*

Others merely considered larviciding as a potent option to reduce outdoor biting populations, or target populations in which pyrethroid resistance is a major issue.

Box 6. ***Should additional vector control tools for Africa include larviciding?***

- Virtually all respondents agreed that there is a need for vector control tools beyond LLINs and IRS.
- Respondents indicated that historically speaking, with a rare exception, countries only succeeded in malaria elimination when they included some form of LSM (including larviciding).
- The vast majority of respondents consider some form of area-wide application of LSM/larviciding as necessary to accomplish malaria elimination in SSA.

6.2.3. Why has larviciding not been adopted and implemented on a large scale in Africa?

When asked if there is sufficient evidence that larviciding can be used in a cost-efficient manner in the African context, experts agreed (80%) but the broader community less so (30%; 34% indicated 'No', 36% 'don't know). This is an area where apparently there is a lack of understanding or absence of in-depth knowledge to make an informed decision, at least within the community. When the experts were asked to indicate what they see as the main reasons why adoption has been slow and implementation on a large scale has not been forthcoming, they indicated a variety of reasons but some comments were commonly mentioned. Out of 16 responses, 10 pointed at decision- and policy makers, the existent policy that apparently is not supportive, ignorance, lack of knowledge and understanding with policy makers and donor/funders. One expert (from Africa) claimed:

> *"The economic costing evaluation of LSM has been recently completed. The results of this indicates that LSM bears acceptable costs, LSM be advocated for at the highest research and policy level as an effective intervention in mosquito vector control and therefore the need for advocacy for donor support for LSM interventions to be scaled up and sustained. The main reason why larviciding has not been adopted and implemented widely in Africa is because of lack of commitment by the donors/funders. If it worked in Israel, Europe and*

> *America, why not Africa. What is so different in Africa that is not so in areas where it was controlled. Africa is ready to move forward only if it gets the support required."*

Some comments used even stronger language and clearly there is frustration amongst experts. Here's what another expert added as reasons for non-adoption:

> *1) Ignorance of policy makers towards historical and recent research findings, (2) Decision makers lack practical expertise in larviciding and do rarely consult those that have such expertise, i.e. in other mosquito control programmes worldwide, (3) The implementation of programmes is considered too costly and too involving, (4) Many small projects and larviciding activities in countries are not well done due to lack of training and expertise, leaving policy makers believe it does not work, (5) Because the intervention is not supported by WHO and in fact countries that wish to do larviciding are reminded by WHO that they are not supposed to use their donor funding for an intervention they do not fully endorse.*

Some mention technical or operational issues like mapping, the fact that larviciding is labour intensive, or it requiring specialist input and extensive training.

Of the experts that did not consider there to be sufficient evidence that larviciding can make a significant and cost-effective contribution, the reasons given were a) limited studies, in different settings, b) lack of a solid evidence base for epidemiological impact, c) logistical problems (manpower needed, monitoring, routine programme implementation), and d) frequency of larvicide application. One expert considered this a 'research gap'.

When asked more or less the same question in a different manner 'Larviciding used to play a prominent role in malaria vector control in many parts of the world, albeit less so in sub-Saharan Africa. What do you consider the main reasons why it has not become 'mainstream' in Africa?' answers were pretty much the same (i.e., lack of evidence, lack of governmental support, policy interfering with uptake and implementation, lack of funding and WHO's view).

6.2.4. What have we learned from historical larviciding campaigns?

There are a number of malaria control/elimination campaigns that surface time and again in publications on larviciding, notably the famous Garki project, the elimination of an invasion of the African malaria *An. arabiensis* in Brazil, the elimination of malaria from Egypt, and the elimination of malaria from Palestine.

The **Garki Project** was a study carried out in the Garki District of northern Nigeria in 1969-76. The Project was the most comprehensive study of the effects of IRS and mass drug administration (MDA) on malaria transmission. The project aimed to measure the effect of house-spraying with propoxur (to control the vectors *An. gambiae* and *An. arabiensis*) alone or in combination with MDA, but LSM/larviciding were not included. The experts were asked to consider if elimination of malaria might have succeeded if larvidicing/LSM would have been included.

The **elimination of *An. arabiensis* from Brazil**, where it invaded an area of 54.000 km^2 between 1930 and 1938, was a massive campaign that was successful after only 18 month of intense control efforts that almost exclusively focused on larviciding (with Paris green). Experts were asked if this success actually showed that (African) malaria vector elimination over large areas is feasible. Malaria was eliminated from **Egypt** during the height of WWII, by applying rigorous larviciding in combination with the then recently discovered DDT. Experts were asked if this is sufficient proof that under specific conditions, also in Africa, larviciding has great potential in malaria control/elimination.

Finally, experts were asked if the **elimination of malaria from Palestine**, where *P. falciparum* prevalence was higher than in many African settings today, with IVM and larviciding as a major component, is additional proof to support larviciding in Africa?

Table. 1. Response (%, n=19) from experts regarding historical campaigns/programmes.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Weighted Average
Nigeria	0.0	5.3	42.1	42.1	10.5	3.58[2]
Brazil	0.0	10.5	36.8	36.8	15.8	3.58
Egypt	0.0	10.5	15.8	42.1	31.9	3.95
Palestine	0.0	10.5	26.3	36.8	26.3	3.79

It is noteworthy that the weighted average for all of these campaigns is 3.5 or higher, indicating that the majority is in 'agreement' with these statements. Equally interesting: None of the experts strongly disagreed with any of these statements.

6.2.5. What did modeling bring us?

The Ross-Macdonald model argued in the 1950s that the focus should be on reducing the adult daily survival of mosquitoes, which ultimately resulted in the tools we have today – LLINs and IRS. Measures aimed at immature stages therefore became less important. When experts were asked if it was right to move away from LSM/larviciding, a surprisingly high percentage (79%) did not agree. Various reasons for this view were given, some of which are worth mentioning here. First, it was argued that the model was not wrong, but that the focus led to interest in a few of the key parameters only even though reductions in the other parameters could equally well contribute to transmission control. Several experts mentioned the weakness of models in that these are helpful from the theoretical point of view, but hardly take into account that the reality is often very much different (and influenced by factors like resistance, incomplete coverage, outdoor biting, behavioural avoidance, etc.). One expert said:

> *"I believe in Macdonald's sensitivity analysis, but in the end, while malaria 'disease' is a medical phenomenon, malaria 'transmission' is an ecological phenomenon and we need to consider the environmental determinants and not just the mathematical dynamics of individual parameters."*

6.2.6. Triple-F strategy: Sense or nonsense?

The WHO LSM manual of 2013 states that LSM is only recommended in places where larval breeding sites are 'few, fixed, and findable'. When experts and the community were asked if they agree with this policy, 56% and 42% indicated 'No', respectively. These views were not strong and there appear to be different views on this topic. Experts commented in favour of the 3F strategy based on lack of efficacy and sustainability, the need for effective M&E, and lack of evidence of cost-effectiveness for areas with many and dispersed breeding sites.

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[2] Weighted average = (w_1n_1 + w_2n_2 +...w_xw_x)/total, whereby the number of most preferred answer (w_1) receives the highest score (n_1=5), and the least preferred answer the lowest (1).

Experts that argued against the policy claimed that 'few, fixed, and findable' is not a meaningful statement, merely causing confusion amongst those that might benefit from LSM:

> *"Cattle hoof prints are often used as an example of not-few, but aggregations of these small sites can be treated in a single swath of spray or granules. Conversely, a giant river floodplain can be considered few, it is certainly findable, and while seasonally variable, it is fixed. Successful LSM studies have demonstrated control in both urban and rural settings where sources cannot be considered few, fixed or findable. They change with seasonal rainfall and human land use. These sources have been controlled by organized programs where local knowledge has been employed to systematically identify and control sources. A better definition is needed."*

There is clearly a need for better definition. By rephrasing this recommendation, many more countries, so one expert argued, would actively evaluate in which areas in their country larviciding might be a useful additional tool, but currently "they are completely put off".

Respondents clearly see the role of WHO in furthering the uptake of larviciding as highly important. Put differently, the policy (mostly sets of recommendations) developed in Geneva strongly influences what member states actually can, will, or wish to undertake in terms of vector control. Two-thirds of the experts and 59% of the community see it as a requirement that WHO alters its policy in order to expand LSM/larviciding as a strategy that can augment currently recommended tools. Experts consider it important that WHO encourages the approach in order to enthuse donors/funding organizations; they consider that the latter parties will mostly move based on WHO recommendation. Any hesitance on the side of WHO, therefore, will result in risk-averse responses from donors. Yet others see sufficient manoeuvring space in the WHO policy documents:

> *"I think there is enough wiggle room in various WHO policy documents that we can press forward. It is really more of a matter of leadership. Look at MDA: there are a thousand times more reasons against MDA but yet that seems to be inching forward. Look for ways to get the camel's nose under the tent."*

6.2.7. Who should drive it forward and who should implement it?

There appears to be a strong conviction amongst all respondents that larviciding should be implemented through community engagement (94% of the experts, 95% of the malaria community). Creating a sense of ownership, knowledge about the terrain in the vicinity of villages, support with finding of breeding sites, and cost-effectiveness were mentioned as reasons why community engagement would benefit larviciding programmes. It was acknowledged though, that larvidicing as an operation needs guidance and control, and cannot just be handed over to communities. In that sense larviciding lies somewhere in between LLINs and IRS, the former not requiring any control or follow up, the latter hardly conceivable through community engagement.

There appears to be considerable misinterpretation regarding the term 'community engagement'. From comments received it appears as if this is mostly seen as 'hands on', being engaged in the field in treating breeding sites. The term is much broader though, and encompasses elements like community acceptance and consent, all the way to community participation and community empowerment and leadership. On the basis of the feedback received it is safe to assume that there is general consensus that the community should, at minimum, be informed (passive engagement) and that further participation is desirable for various reasons but may happen at different levels of intensity.

When asked who should drive the approach forward, a variety of choices came forward as shown in Table 2.

Table. 2. Response (%) from experts and malaria community regarding the question 'Who should drive the adoption of larviciding in African countries?'.

Answer Choices	Experts (n=18)	Malaria community (n=242)
Governments - MoH	94.4%	77.3%
NGO's	50.0%	49.2%
Private sector	38.9%	34.7%
Community groups	61.11%	51.2%

The options selected were very much similar between the experts and the community. Both groups consider the uptake and drive towards wider implementation of larviciding to be primarily a responsibility of governments. A secondary role is seen for NGO's and the private sector, followed by community groups.

6.2.8. What are the major hurdles in order to move forward?

Although there was wide support for the statement that 'If well organized and implemented, the impact of larviciding on malaria in sub-Saharan Africa can be substantial if not significant', i.e. 94% of the experts and 81% of the community, there were a number of reasons that were seen as hindering progress. Two-thirds of the experts considered operational complexity to be an issue, followed by high cost (39%; 27% for the community) and lack of a strong evidence base (33%; 59% for the community).

Table. 3. Response (%, n=246) from malaria community regarding the question 'Larviding is…'

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Weighted Average
Too expensive	9.8	30.9	30.9	23.6	4.9	2.83
Operationally complex	7.7	27.2	12.2	36.6	16.3	3.26
Only feasible in specific places	4.1	17.1	14.6	48.4	15.9	3.55
Needs better (residual) larvicides	4.9	11.8	18.7	44.3	20.3	3.63
Should be prioritized in malaria control	5.3	14.7	28.9	32.5	18.7	3.45
Needs more evidence before broad adoption	4.9	19.5	16.7	39.8	19.1	3.49

Interestingly, only 2 out of the 18 (11%) experts consider the absence of effective and long-lasting larvicides as a hurdle. This contrasts strongly with the community view, whereby 65% of the respondents agree or strongly agree that we need better (residual larvicides).

Table 3 lists the views from the malaria community regarding certain aspects of larviciding. The weighted scores in this Table indicate that apart from the question about cost (which was slightly skewed towards 'disagree', all questions were skewed towards 'agree'. In other words, the malaria community considers (like the experts) larviciding to be a complex undertaking, it believes that it is suitable only for specific places, that it needs better larvicides and needs additional evidence before being implemented on a large(r) scale. Noteworthy then is agreement with the view that it should be prioritized in malaria control.

Other hurdles that were mentioned by the experts were absence of political will and global policy, and the concept of 'few, fixed, and findable', which was considered an obstacle.

All the experts (100%) agreed that larviciding should be undertaken as part of an IVM package. They also consider it comparatively easier to train personnel for larviciding than for IRS, mainly because the latter technique involves working with and possible exposure to more toxic chemicals than the biological control agents used for larviciding. Others claimed that training may not be difficult but supervision and quality assurance may be. Half the experts consider the operational aspect of knowing where, when and how often to use larvicides more complex than knowing where, when, and how often to implement IRS. Obviously, houses are more fixed than breeding sites, are much more permanent than water bodies, and have an indoor dry environment and a few options for wall surfaces, which is much less variable than the variation observed in water bodies harbouring larvae. Thus, predicting where the larvae are may be more difficult than predicting where the adult mosquitoes are.

Regarding (larvicide) application equipment there is general agreement amongst the experts (72%) that there is a good variety of tools available for larviciding. An even higher percentage (89%) agrees that we currently have a nice package of (biological) larvicides to move forward with. Bti was specifically mentioned, as well as the various formulations thereof. Several respondents referred to the need for longer-lasting formulations of larvicides, and although new long-lasting formulations have recently been tested successfully (Afrane et al., 2016), there were requests for more field evidence.

6.2.9. Is there need for a policy change?

Both the experts (83%) and malaria community (90%) concurred that malaria elimination in Africa demands tools that can be used in the outdoor environment beyond the confines of the house. Of the experts, 67% see it as a requirement that in order to move larviciding forward WHO changes its policy on LSM (this is slightly lower for the community, 59%). Various reasons were listed as to why the 3-F strategy is not helpful in guiding decision on malaria vector control. Two-thirds of the experts see larviciding as an effective option for both the wet and dry seasons, although issues regarding cost and implementation will be affected by local ecology and epidemiology.

Finally, respondents considered policy barriers as slightly more important than technological and operational barriers (weighted average 3.33), consider linkage of vector control to wider socio-economic development as highly important (weighted average 4.11), but also see the need for champions to step forward and drive larval control forward (weighted average 3.83). Strikingly, a score of 3.94 as a response to the statement 'We have enough, let's get on with it', speaks for itself – this response reflects the views from researchers, donors, industry representatives, and larval control experts.

6.3. Porter's five forces analysis

Porter identifies five forces that shape every industry (in this case the 'industry' of malaria vector control in Africa) and which determine the intensity and direction of competition and therefore the profitability of an industry component (in this case LSM/larviciding). The objective of strategic planning (the gap analysis and change management proposal) is to modify these competitive forces such that the position of those engaged in larviciding is improved. Stakeholders engaged in it can then decide, based on the information given by the Five Forces model, how to influence or to exploit industry characteristics.

6.3.1. Rivalry within the malaria vector control field

Two tools dominate the field of malaria vector control in Africa: LLINs and IRS. Although the paucity of tools would, *a priori*, hint at the existence of great market potential for additional tools (and thus products), market entry is elaborate, time-consuming and complex, which keeps rivalry within the vector control field limited. WHO policy, which results in 'recommendations' for certain tools, products, or processes, has a strong influence on the size of and major players in the market, since major funding organizations will primarily (if not only) purchase product that is WHO-recommended. Given the fact that the process to obtain WHO-recommendation (through WHOPES and/or VCAG/Prequalification) is very time-consuming, there is little fear amongst incumbents that new technology will start competing for market share. Rivalry within the sector is influenced through tendering processes, which keeps profitability of LLINs low, thereby reducing attractiveness of these products for newcomers. Conversely, the high concentration of the LLIN industry (limited to a handful of large manufacturers in Southeast Asia and one in Africa) indicates less competition; a small number of firms hold most of the market share and have WHOPES recommendation for their product, thereby keeping new entrants in the market at bay.

Continuous innovation, largely driven by the presence and further spread and increase of resistance of vectors across Africa to commonly used insecticides (either on nets or on walls) may generate short-term strategic advances and profitability although, for instance, the market for 3^{rd}-generation bednets (i.e. with multiple active ingredients) became saturated within ten years. Market entry is strongly affected by WHOPES/VCAG policies. Direct country registration of new products is likely to happen when the demand for novel vector control tools exceeds the ability of countries to maintain vector control at satisfactory levels with the tools at hand.

Competition with LLINs/IRS is likely to increase when novel tools effectively address the shortcomings of these tools, notably curb insecticide resistance, address behavioural avoidance, and/or are effective against outdoor biting vector populations. Odour-baited traps, ATSBs, eave tubes, and spatial repellents, amongst other promising options, may see a market developing, but require epidemiological evidence prior to obtaining 'WHO recommendation', which necessitates (often costly) Phase III RCTs or equivalent approaches to demonstrate (cost)effectiveness and unequivocal public health benefits.

Given the important role that vector control has played over the last fifteen years, it is likely that its role will increase (in terms of market size) but that the number of tools that will be implemented besides LLINs/IRS will remain limited for the time to come. Whether or not genetic vector control strategies will play a role in this field remains unknown at this stage, since no evidence for effectiveness under field conditions is available at present.

In the wider field of malaria control and elimination efforts there are strong competitive forces (sometimes referred to as Porter's sixth force) that will affect the potential for LSM/larviciding in the near future. Although malaria prevention used to be limited to vector control, current developments in the field of drug use to prevent infection, as well as vaccine developments, can be expected to start influencing resources available for vector control. Seasonal malaria chemoprevention (SMC), mass drug administration (MDA), and various forms of Intermittent Preventive Treatment (IPT), will play an increasingly big role in parts of Africa (for SMC and MDA notably in regions with seasonal and/or low transmission intensity). The upcoming trials with the RTS,S vaccine in Ghana, Kenya, and Malawi, if capable of showing significant health benefits in targeted age cohorts, are likely to shift financial resources from vector control to vaccination in future unless (inter)national funding for malaria control/elimination will increase significantly.

Alternatively, if an approach or combination of tools will be capable of driving transmission to zero and is applicable across much of Africa, such an approach will very likely disrupt the market and draw resources now invested in other approaches. Considering that larviciding has played such a dominant role in countries that succeeded with malaria elimination, and that most of those interviewed during the survey reported here actually believe that elimination cannot succeed *without* it, building a strong market position should be possible. If anything, gaining a competitive position based on historical successes (of which there are several that are considered good evidence in the current survey), especially in view of other strategies that have never been field-tested or evaluated in terms of public health impact, should be straightforward. What is missing, though, is solid proof that such an integrated approach, which includes larviciding, will result in (local) elimination. Getting that proof will be instrumental in gaining broader interest in larviciding and drawing attention from donors and policy makers.

6.3.2. Threat of new entrants

The threat of new players entering the field of malaria vector control in Africa is limited. The barriers to entry are significant regarding LLIN/IRS products due to concentration of the industry, scale economies and brand equity enjoyed by incumbents, low profit margins, and regulatory issues (i.e. obtaining WHOPES/VCAG recommendation). This results in the sustained dominance of an oligopoly of companies that has long time windows available to bring new product to market and have strong financial (R&D) capabilities. Moreover, given the comparative size of the overall market of malaria vector control, which is very small in view of the agrochemical market for instance, the attractiveness to enter the market is limited for companies with a sole focus on vector control.

New entrants could benefit from introducing solutions to problems faced by incumbents, notably insecticide resistance. However, R&D initiatives that are heavily funded from outside the industry to discover new public health insecticides and bring these to market have reduced the threat of new entrants for incumbents like Bayer, Syngenta, Sumitomo, BASF, and others. Such developments, whereby industry competition is artificially reduced through donor funding (e.g. through the Bill & Melinda Gates Foundation) hinder newcomers from entering the market with novel solutions. Such financial injections in R&D for incumbents drive new players in the same direction because it will be difficult to obtain significant funding (e.g. through venture capital) since the future of innovative tools resides in the hands of a small group of individuals and/or expert committees and their personal/organizational stakes.

6.3.3. Power of suppliers

Larviciding depends on the availability of larvicides – and in the case of larviciding against malaria vectors in Africa, this predominantly means the bacterial larvicides that have received WHOPES recommendation (*Bacillus thuringiensis israelensis,* strain AM65-52)[64]. The power of suppliers is strong, since there are only few. For some (granular) formulations that have received WHOPES recommendation there is only a single manufacturer, which therefore has market dominance and considerable bargaining power, especially in programmes funded by organizations that will only purchase WHO-recommended product (like the Global Fund or PMI).

Beyond microbial larvicides there is growing interest in IGRs, notably pyriproxyfen, for the control of malaria vectors, as well as monomolecular films. These, however, will require a stronger evidence base before being applied on a larger scale. Competition on the side of suppliers will increase when new products, and especially new (long-lasting) formulations are being developed. Cost-effectiveness, residual activity and safety will be key factors driving innovation and fuelling competition amongst suppliers.

With regards to larvicide application equipment, the number of players in the field is also rather limited. Competition amongst them is based on price and quality and is not linked to regulatory requirements.

6.3.4. Power of users/consumers

Larvicides and equipment to apply these are not purchased by individual household owners or even at community level but rather through implementing agencies or vector control programmes (e.g. vector control activities residing under the NMCPs). Their bargaining power is very limited, especially when using funding on which the donor has placed restrictions regarding the choice of larvicide and/or application equipment. Considering that the market for larviciding is still very small, that product choice is restricted due to donor and regulatory requirements, that manufacturing mostly occurs outside Africa, and that only few manufacturers distribute product, makes the competitive position of users very weak.

6.3.5. Threat of substitutes

Substitute vector control products that may compete for resources/market share in the near future are mentioned above. The need for new tools to control outdoor and/or residual transmission that go beyond LLINs/IRS is evident and widely acknowledged (see 4.2.2.), and may include larviciding. Alternative vector control tools that may be used beyond the intra-domiciliary domain are area-wide fogging (not in use at the moment but does play a role in the control of culicine populations outside Africa), aerial applications of insecticides (not currently practiced for malaria vector control in Africa), or genetic vector control. Within this latter field, the development of the Sterile Insect Technique (SIT) had been underway for nearly 15 years now, without any field implementation as yet. Regarding genetic control that utilises gene drive (incorporating the latest gene drive techniques such as CRISPR-Cas9), there is no evidence yet that such an approach can work under field conditions although preparations for field evaluation are underway. If such an approach shows promise and can be shown to reduce disease morbidity and mortality in the field, it may become a strong competitor for larviciding or other outdoor/area-wide control efforts.

6.4. Gap analysis framework

In the gap analysis framework on the following page/s, reference is made to the online surveys in the 'Feedback survey(s)' column. Reference to the survey amongst experts/NMCP managers (see Appendix 2 for the questions & answers) is shown as, for instance, 2Q1, which is referring to question 1 in appendix 2. Likewise, for the survey amongst MalariaWorld/VCWG members (questions & answers in Appendix 3), it is shown as, for instance 3Q4, referring to question 4 in appendix 3. Experts and NMCP managers are collectively referred to as 'experts'. The MalariaWorld/VCWG members are referred to as 'community'.

An additional framework based on the outcome of the Porter's Five forces analysis is added below the gap analysis framework.

Desirable or future state	Current state	Defined gap(s)	Feedback survey(s)	Proposed action(s)	STEEP
Inclusion of important stakeholders in larviciding operations ensured, which enables broad(er) scale operations in many parts of Africa.	Not clear who needs to be involved, in what, and to what extent.	Role assignment and task delegation to different stakeholders not clear.	Experts (94.4%, 2Q20) and community (94.6%, 3Q10) agree that larviciding should be implemented with community engagement.	Develop strategies for community engagement/participation. Seek hybrid forms between bottom-up and vertical programmes to develop novel implementation models.	S
Broad acknowledgement amongst all stakeholders that vector control tools beyond LLINs and IRS are needed.	Heavy focus on up-scaling existing technologies and less regard for LSM & larviciding.	The belief that malaria can be eliminated with the current tools needs to be refuted.	All experts (100%, 2Q1) and community (94.0%, 3Q1) acknowledge the need for new vector control tools.	No immediate need. The notion that new/better tools are needed is widely endorsed.	T,P
Appreciation for the fact that elimination cannot be accomplished without larval source management as an integral component.	Role of LSM and larviciding limited and not strategically incorporated in elimination efforts.	Many stakeholders disapprove of the critical role of LSM and larviciding in elimination.	All experts (100%, 2Q4) and community (92.7%, 3Q2) indicate that they don't know where elimination succeeded without LSM.	Demonstration efforts to prove feasibility of malaria elimination when LSM is included.	T
Inclusion of larviciding in vector control operations is based on pragmatism and cost-effectiveness.	Larviciding is often discarded on the basis of the Ross-MacDonald model.	Current generation of malariologists and control specialists almost dogmatically focus on controlling adult females *Anopheles.*	79.0% of experts agree that moving away from larviciding based on the Ross-MacDonald model was not right (2Q14).	Use models in teaching/training curricula to demonstrate the possible impact of larviciding and not just LLINs/IRS.	T
Broad understanding that larviciding can be a cost-effective strategy.	Larviciding is often seen as too expensive and not cost-effective.	Insufficient understanding that larviciding can be cost-effective amongst broader malaria (vector) community.	Experts (80.0%; 2Q9) convinced of cost-effectiveness, community not (30.0%; 3Q5)	More outreach/demonstration on the cost-effectiveness within the malaria community (and possibly other stakeholders like gov'ts and funding agencies).	E
Larviciding does not have to be more expensive than other vector control tools and can be equally effective.	Many stakeholders consider larviciding too expensive	Insufficient knowledge on cost of larviciding; persisting views that can be challenged.	Experts (38.9%; 2Q24), community 'agrees' or 'strongly agrees' it is too expensive (28.5%; 3Q8)	One third of experts and malaria community not convinced about cost-effectiveness. Need to be better informed.	E

Desirable or future state	Current state	Defined gap(s)	Feedback survey(s)	Proposed action(s)	STEEP
Broad appreciation for historical successes in malaria control/elimination based (primarily) on larviciding.	Scepticism towards or lack of knowledge about successful historical campaigns.	Absence of understanding or unawareness of historical campaigns.	Experts (2Q13) support the notion that these campaigns provide evidence of the potential of larviciding.	More attention needs to be drawn to historical campaigns and the successes these delivered in malaria control and elimination (book, film documentary?).	P
Broad acknowledgement amongst key stakeholders that LSM, and larviciding in particular, has a key role to play in malaria elimination.	Key stakeholders focus mostly on LLINs & IRS and novel tools other than larviciding.	Insufficient appreciation of the role of larvidicing, ignorance of the evidence base available, lack of updated knowledge of new developments in larviciding.	Experts (95.2%; 2Q6) and community (69.7%; 3Q4) indicate that malaria elimination in Africa will only succeed with area-wide control efforts against larval stages.	Close knowledge gap by informing key stakeholders about the (historical) evidence of LSM/larviciding. Not just through scientific publications but modern communication strategies.	P
Broad acknowledgement amongst key stakeholders that LSM, and larviciding in particular, has a key role to play in malaria elimination.	Little appreciation or knowledge available amongst stakeholders on historical campaigns that were based on larviciding.	Contemporary malaria (vector) control efforts lack information about historical approaches like larviciding (we 'de-learned' it).	Experts 'agree' or 'strongly agree' that the campaigns in Brazil (52.6%), Egypt (74.0%) or Palestine (63.2%) prove that larviciding can work (2Q13)	Collate (and publish) evidence from historical campaigns (mostly) based on larviciding and/or LSM and circulate amongst NMCPs and academics.	P
Larviciding is a broadly implemented vector control tool that augments existing tools and contributes significantly to malaria elimination.	Larviciding plays a relatively minor role, in specific settings only, on a limited (experimental) scale.	Larviciding is not prioritised as a tool of choice to be implemented besides LLINs and IRS.	Experts (94.4%; 2Q27) and community (80.6%; 3Q12) believe the impact of larviciding (if well organised) can be significant.	Better communication of the role of larviciding in comparison with new (and yet unproven) vector control tools that donors and policy makers focus on at present.	P
The triple-F strategy of focusing only on breeding sites that are 'few, fixed, and findable' is broadened to encompass wider areas.	The triple-F strategy impedes broad-scale implementation of larviciding.	WHO recommendation is not conducive to wider experimentation and implementation of LSM/larviciding.	Experts (66.7%; 2Q45) and community (59.1%; 3Q7) recommend change in WHO policy. 49.4% of community agrees with current WHO 3-F policy (3Q6).	VCWG and other bodies to collaborate with WHO to release an updated recommendation document or position statement.	P

Desirable or future state	Current state	Defined gap(s)	Feedback survey(s)	Proposed action(s)	STEEP
Larviciding is a 'mature' vector control tool that is accepted as a mainstream malaria control tool.	The broader community is not convinced that larviciding is sufficiently evidence-based to move forward with.	Knowledge gap – unlike the experts/NMCP managers, the broader malaria community is not well informed.	Of the experts, 44.4% 'strongly agree' that we have enough evidence 'to get on with it' (2Q47). This is only 19.1% in the community (3Q8).	Significant knowledge gap between experts/managers and broader community needs to be closed.	P
Larviciding is driven and supported by the most suitable organisations.	Dispersed actions by loosely connected groups often driven by champions.	Coordinated agreement on who takes responsibility for executing larviciding campaigns.	Govt's, NGO's, community groups all more than 50% chosen as drivers (2Q23; 3Q9). Community sees role for WHO (61.6%).	Clearly define roles and responsibilities of different stakeholders in larviciding campaigns.	P

Desirable or future state	Current state	Defined gap(s)	Proposed action(s)	Porter
Larviciding is a widely adopted and accepted malaria vector control tool in Africa.	Vector control is dominated by two tools (LLINs/IRS) and market entry for new approaches is difficult.	Current legislation and requirements stipulated by WHOPES/VCAG, donors, or policy bodies (e.g. WHO/GMP) slow down wider adoption	Facilitate more rapid adoption of new vector control tools (in general, but LSM in particular). Facilitate market entry by smaller companies to widen the product array moving towards field implementation. Do not selectively favour large chemical companies to drive innovation forward. Let the market decide what products are wanted, not a few individuals or small expert committees. Promote product innovation and competitiveness, don't stifle it.	Rivalry
Larviciding and other vector control tools continue to play a dominant role in elimination efforts.	Risk that drug and vaccine-based approaches will draw resources away from vector control.	More emphasis on the proven role of vector control, and in particular larviciding needed.	There needs to be much more awareness of the importance of vector control in vector-borne disease elimination. Now that vaccine- and drug-based interventions are moving to scale in the field, vector control should not be hijacked by patient-oriented approaches.	Rivalry
Larviciding is widely acknowledged to play a critical role in malaria elimination.	There is no solid proof that a 'package' of tools that includes larviciding can be used to eliminate malaria in a variety of settings in sub-Saharan Africa.	There is an urgent need to demonstrate that larviciding, in combination with other tools', can be used to reduce transmission to zero.	Establish proof of principle projects across various ecological settings in Africa, like the historical Garki project, where a set of tools that includes larviciding, is implemented in such way that malaria is (durably) eliminated.	Rivalry

Desirable or future state	Current state	Defined gap(s)	Proposed action(s)	Porter
Larviciding and vector control tool development is supported by a wide array of product developers and companies.	The field is dominated by few large (chemical) companies.	SMEs cannot serve the vector control market due to dominance of the well-funded large players in an oligopoly.	Increase the number of SMEs that focus on vector control products and facilitate their participation through market entry and development. Speed up regulatory and registration processes.	New en-trants
There is a broad range of larvicide suppliers that continuously innovate to compete in the market, thereby introducing high-quality product at affordable prices.	A few companies dominate the market.	Innovation (e.g. developing long-lasting formulations) is not encouraged.	Stimulate innovation through creation of an enabling environment in which uptake of new technology and/or approaches is promoted and supported.	Suppliers
NMCPs and other vector control programmes have a wide choice of products for larviciding.	A few companies dominate the market.	Market dominance inhibits product diversification and price competition.	Faster throughput of the product development pipeline. Facilitate market entry and consider implementation based on new models to determine cost-effectiveness and safety rather than elaborate, costly and time-consuming RCTs.	Consumers
Larviciding is considered an integral component of malaria (vector) elimination campaigns.	New technologies, notably genetic control strategies may compete strongly with larviciding.	Appeal of new (bio)technologies threatens to outweigh power of proven concepts.	Safeguard, as a guiding coalition (section 7), that resources that should be devoted to larviciding are not being diverted to other (genetic) control strategies.	Substitutes

7. Recommendations: Implementing the change

The foregoing analyses (Literature, STEEP, questionnaires, Porter's five forces, and gap analysis) have resulted in the identification of several gaps that need to be bridged in order to move LSM/larviciding forward to become a mainstream vector control tool in Africa in aid of malaria elimination. The sections below provide advice on how these gaps may be addressed according to Kotter's 8-step model of change (see Figure). A critical first step in this process is to *create a climate for change*, which encompasses creating a sense of urgency (section 7.1), for a powerful coalition (7.2) and create a vision for change (7.3).

7.1. Creating a sense of urgency for larviciding is easy

There are several reasons why there is urgency regarding the wider implementation and evaluation of LSM/larviciding as a vector control tool in Africa. First and foremost, there is consensus that malaria elimination in Africa with the vector control tools currently available will not be adequate (in most parts of the continent) to drive transmission down to zero and eliminate malaria. There is therefore a need for a logical next step.

Given the problems associated with insecticide resistance, there is concern that the current tools (notably IRS and LLINs) may no longer be as (cost)effective unless we see these tools deploy novel public health insecticides within the next few years. But even if there will be new insecticides for indoor use, there will be mounting problems with (partially) outdoor biting populations and partially zoophlic populations that will be less affected by these new insecticides than the more endophilic and anthropophilic species.

The sense of urgency is present, and was an unambiguous outcome of the surveys reported above. We need new tools, and we need to be able to use them outdoors as well if we are to significantly impact malaria transmission in major parts of Africa. Certainly the experts no longer doubt the role that LSM/larviciding can and should play. If 72% of them agree/strongly agree with the statement 'We have enough evidence, let's get on with it', then there appears to be little reservation regarding the potential of this approach.

However, a shortcoming of the present online surveys is the fact that often only those with a sincere interest in this approach will actually fill out the questionnaire, causing bias in the outcome of the study. Those that have no faith in the approach and favour alternative (novel) strategies may simply have ignored the opportunity to ventilate their views and concerns. The key message from all this is that although there is a (growing) group of people that have confidence in LSM/larviciding, this is not yet broadly shared amongst stakeholders that have an important say in the selection and choice of vector control tools that will be deployed and/or further developed. In other words, if the vast majority of respondents see it as the government's role to drive LSM/larviciding forward, then who will provide them with the right information, the operational framework, and other resources? If NMCPs are interested in wider implementation of LSM/larviciding, then who will provide the funds to do so?

In conclusion, it is obvious that there is a sense of urgency, but that this will only become a real opportunity if it is broadly communicated amongst stakeholders. Maturation of the approach for implementation in Africa requires an open dialogue and should take place within the framework of IVM. A clear threat in this regard is the looming impact of drug-based and possible future vaccine-based strategies that may draw significant resources from vector control and result in a collapse of the sense of urgency amongst key players. For now, the insecticide resistance crisis, coupled with the potential and sustainability of new formulations of biological control agents, provide major advantages that can be exploited to bring the approach to the forefront.

7.2. Build a guiding coalition of LSM experts and NMCP champions

Change requires individuals, teams, or groups that drive change efforts forward. Critical is not only to have supporters but to have supporters that actually have the power and ability to induce the change – they need to be champions and change agents at the same time. The survey that was held amongst experts in this field had a variety of people with different functions involved, which included academics, donors, policy makers, industry representatives, etc. Considering their strikingly similar views with regards to many issues that were addressed in the survey, coupled with their expertise in this field, this group may be approached to form an expert group that can drive the change.

Although the response from NMCP managers was very low, given the fact that a considerable number of African countries are already on a smaller or larger scale implementing larviciding, champions within the NMCP of *each* African country may be sought and included in a united African group to drive the approach forward. Combined, the experts and NMCP staff can form a powerful coalition to bridge the identified gaps.

Such a coalition could meet in break-out sessions during existing meetings and conferences like the annual VCWG meetings in Geneva, the Pan African Mosquito Control Association (PAMCA) conferences, or the ASTMH annual conferences. A base for the coalition (e.g. PAMCA) ought to be established and would likely best be placed in West, East, and Southern Africa.

In conclusion, the existing force of proponents and parties interested in larviciding is currently too fragmented, not (or only limited) coordinated, and not empowered or sufficiently enabled to drive the change. A coalition of those that have the power, will, and ability to drive the change, augmented with and supported by an Africa-wide coalition of NMCP-based champions, is therefore needed.

7.3. Form a strategic vision and initiatives

Once a critical mass of people that can drive the change forward has been established, they are tasked with drawing up a strategy for wider implementation of larviciding. Much of this is already available in fragmented (policy) documents, IVM guidelines, etc. but needs to be communicated in a much more powerful and actionable manner. Countries need to be presented with clear and simple steps to follow in order to progress their efforts in larviciding.

A clear vision on the future role of larviciding needs to be stipulated and communicated to all stakeholders involved. More so, the vision needs to be translated into strategies that are appropriate for specific settings and should provide guidance in such manner that NMCPs and other implementing parties in each country know how to proceed and at the same time initiate a monitoring and evaluation programme aligned with that of other countries. The coordination of these efforts should be based at regional level. The vision and strategy derived from it should be compelling, convincing and realistic so that adoption from MoH to grass-root level is unambiguous.

In conclusion, a clear vision and strategy derived from it needs to be drawn up. This can be based on existing (policy) documents, but need to be straightforward and appealing to all stakeholders to embark upon.

The above three steps serve to create an enabling climate for change. These steps can largely be undertaken by a relatively small group of people charged with implementing the change. The next three steps serve to *engage in and enable the change*, which involves a much larger group of stakeholders.

7.4. Enlist a volunteer army

Once the vision and strategy derived from it are available, all channels and options to communicate it to the broader network of stakeholders need to be used. At this stage Ministries of Health and those in charge of vector control therein need to become engaged. This communication, towards a broad group of stakeholders, requires a detailed stakeholder management and communication plan. This is the moment when those enrolled in the initial stages of setting up a guiding coalition need to have all the information they need to enforce the change within their respective settings. The right individuals that can back the change and drive larviciding forward as a new approach need to buy into the new strategy – guided by simple and actionable steps that can be monitored and coordinated at the regional level.

Key here will be to address the gaps identified before, of which the majority are knowledge gaps. Championing the approach, backed with solid information that is both current and accurate, will be essential to create the required 'buy in'. Those that drive the change need to take every opportunity to communicate what the network is up to, what it has accomplished, and how it is driving the change forward.

7.5. Enable action by removing barriers

Getting rid of obstacles will be essential – be these flaws in policy, lack of confidence, scepticism, etc. The network will only be enabled to move the change forward if it is not crippled by doubt and disbelief. Broad-based action should encourage risk taking, activities and action so that the approach can gain popularity and thus confidence. It is again the role of the network's guiding coalition to support those that encounter 'resistance to change', which is to be expected since out-dated dogma's (e.g. 'it is too expensive', or 'mosquitoes breed everywhere') will persist until new evidence prove them wrong.

7.6. Generate short-term wins

Perhaps the most important way forward for larviciding will be to broaden the evidence base. A Cochrane review may not have been sufficiently convincing, but pilot projects run simultaneously across a range of settings (urban/rural, seasonal/perennial, etc.) may change perception amongst those in doubt. This would repeat the approach that was taken during the mid-1990s when across Africa trials with insecticide-treated bednets were run to confirm their potential across a range of transmission settings. A similar approach with larviciding would be extremely powerful and should be based on an integrated approach with a focus on elimination. A few such sites ('Garki 2.0') could change the role of larviciding for good and could elevate it to the same level of importance it enjoys in other parts of the world. The successful implementation of larviciding in rural Burkina Faso [46,47] is apparently not enough so more evidence is needed.

The final two steps focus on *maintaining and sustaining the change*.

7.7. Sustain acceleration

The increased credibility that results from these pilot trials across various settings should serve to consolidate the change – the successes become the drivers to manage prejudice and scepticism. A positive spin on larviciding, backed by solid examples of how it can contribute as part of a vector control package sufficiently strong to reduce transmission to zero, is needed at this stage. By now the approach should reach the same level of recognition as LLINs and IRS have today. Launching new projects and expanding the areas over which larviciding is implemented should now invigorate the process of adoption. The network and guiding coalition is now becoming the change broker and accelerator.

At this stage it is likely that innovation will truly take off. With a growing interest in the approach comes a growing market and therefore the pull for better and novel products (e.g. long-lasting formulations). As with the development of bednets, which took years to reach the current level of sophistication (i.e. from nets that needed to be dipped by hand at 6-month intervals to current LLINs that last an average of 3 years), so will maturation of larviciding take time.

7.8. Institute change

Finally, with more evidence mounting, the role of the initial coalition will reduce in importance. Although they may continue to champion the approach, adoption is no longer an issue. Larviciding will then become as common as it is for many mosquito abatement districts in the USA or the annual larviciding campaigns in Germany's Rhine Valley.

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Appendix 1. Terms of Reference.

Work schedule

Background

Larviciding is an old tool for mosquito control, but so far it hasn't been scaled up widely for malaria control in Africa. There are a number of possible factors that may influence or hamper the wide scale use of larviciding. These include technological factors (application technology, duration of efficacy, locating habitats), delivery system issues (capacity), economic reasons (e.g. price, cost-effectiveness, affordability, financing options), evidence (strength and influence) and policy matters (WHO position statement, policy champion).

A short term consultancy is available to review factors slowing the wide scale use of larviciding for malaria control in Africa. The aims of the consultancy are firstly to identify the factors that positively or negatively influence the scale up of larviciding and secondly to suggest the options to capitalise on or address these.

Proposed Methodology

The consultant will use a combination of desk based methods (literature search and review) and interviews (online surveys or telephone/skype) with key informants (KI). The consultant will contact 3- 4 KIs for unstructured interviews and use these as the basis for setting up a semi-structured questionnaire that can be managed online and sent out to a larger group. Key informants are likely to include: LSM experts, vector control experts (without LSM background); representatives from key funding and policy bodies, NMCPs and the private sector (preferably larvicide manufacturers).

The consultant will propose a methodology for collecting relevant information to address the topic under study. This will include literature review methods (search strategy, search terms, databases to be searched, inclusion/exclusion criteria), suggested participants for the KI interviews and a question guide for the interviews.

The methodology will be reviewed and agreed on with IVCC prior to data collection. Work progress will be discussed weekly between the consultant and IVCC and a final draft of the paper will be submitted to IVCC on 3rd February 2017 for review.

Deliverables

The outcome from this exercise will be a concise white paper showing the current scale of larviciding as an intervention for malaria control in Africa, the factors that positively or negatively influence its scale up and aspects that need to be addressed for this intervention to be widely adopted.
In considering the aspects that need to be improved, a draft Target Product Profile (TPP) will be proposed that could be used by those who want to develop this intervention.

Appendix 2. Questionnaire and answers for 23 experts and 46 NMCP senior staff/managers.

Q1 Over the past 15 years, massive progress has been made in malaria vector control, primarily with two house-based interventions (LLINs and IRS). More than 6 million lives have been saved and some 700 million cases have been averted. In Africa overall, prevalence of P. falciparum in children 2-10 yrs of age has dropped from 33 to 16%. Is there a need for additional vector control tools besides LLINs and IRS? (Answered: 23 / Skipped: 0)

Answer Choices	Responses	n
YES	100.00%	23
NO	0.00%	0
Total		23

Q2 You consider it necessary to add new tools for malaria vector control in Africa. Considering the current problems with existing tools (insecticide resistance, behavioural resistance) what do you see as the most promising add-on tools that may be implementable in sub-Saharan Africa over the next five years, inside or outside the house? Please name these and describe briefly why you consider these promising (Answered: 21 / Skipped: 2)

Q3 You consider the vector control tools we have at the moment sufficient for malaria control in Africa. Do you think that it will be possible to eliminate malaria in sub-Saharan Africa with (next generation) LLINs and/or IRS, perhaps augmented with non-vector control tools like mass drug administration (MDA) or a (future) vaccine? (Answered: 1 / Skipped: 22)

Answer Choices	Responses	n
YES	100.00%	1
NO	0.00%	0
Total		1

Q4 Do you know of countries that have eliminated malaria without some form of larval source management as an integral component of its elimination effort? (Answered: 21 / Skipped: 2)

Answer Choices	Responses	n
YES	0.00%	0
NO	100.00%	21
Total		21

Q5 Please mention the countries that have eliminated malaria without some form of larval source management as an integral component of its elimination effort here: (Answered: 0 / Skipped: 23)

Q6 Will malaria elimination in sub-Saharan countries require some form of area-wide control efforts directed at aquatic stages in order to succeed? (Answered: 21 / Skipped: 2)

Answer Choices	Responses	n
YES	95.24%	20
NO	4.76%	1
Total		21

Q7 Please explain why area-wide larviciding is needed for malaria elimination in sub-Saharan Africa. (Answered: 19 / Skipped: 4)

Q8 Please explain why area-wide larviciding is not needed for malaria elimination in sub-Saharan Africa. (Answered: 1 / Skipped: 22)

Q9 Is there in your opinion enough evidence that larviciding can be used in sub-Saharan Africa in a cost-efficient manner? (Answered: 20 / Skipped: 3)

Answer Choices	Responses	n
YES	80.00%	16
NO	20.00%	4
Total		20

Q10 You consider that larviciding can make a significant and cost-efficient contribution to malaria control in sub-Saharan Africa. What do you consider as the main reasons why larviciding is not adopted and implemented widely? (Answered: 16 / Skipped: 7)

Q11 You consider that there is not enough evidence that larviciding can make a significant and cost-efficient contribution to malaria control in sub-Sahara Africa. Please explain what evidence is lacking? (Answered: 4 / Skipped: 19)

Q12 Larviciding used to play a prominent role in malaria vector control in many parts of the world, albeit less so in sub-Saharan Africa. What do you consider the main reasons why it has not become 'mainstream' in Africa? (Answered: 19 / Skipped: 4)

Q13 Historical examples often surface in discussions on the potential of larval control...
(Answered: 19 / Skipped: 4)

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Total	Weighted Average
If larviciding/IRS would have been added in the Garki project (in Nigeria, 1970s), besides IRS and mass drug administration, elimination could have been achieved.	0.00% 0	5.26% 1	42.11% 8	42.11% 8	10.53% 2	19	3.58
The elimination of An. arabiensis from Brazil unequivocally shows that (African) malaria vector elimination over large areas is possible.	0.00% 0	10.53% 2	36.84% 7	36.84% 7	15.79% 3	19	3.58
Malaria was eliminated from Egypt during WWII with larviciding (and DDT-IRS) as the major tools - this is proof that under specific conditions, also in Africa, larviciding has great potential in malaria control/elimination.	0.00% 0	10.53% 2	15.79% 3	42.11% 8	31.85% 6	19	3.95
In Palestine, P. falciparum prevalence was higher than in many African settings today. IVM, with larviciding as a major component, resulted in the elimination of malaria. Is this additional proof to support larviciding in Africa?	0.00% 0	10.53% 2	26.32% 5	36.84% 7	26.32% 5	19	3.79

Q14 The Ross-MacDonald model argued in the 1950s that the focus should be on reducing the adult daily survival of mosquitoes, which ultimately resulted in the tools we have today – nets and IRS. Measures aimed at immature stages therefore became less important. Was it right to move away from LSM/larviciding? (Answered: 19 / Skipped: 4)

Answer Choices	Responses	n
YES	21.05%	4
NO	78.95%	15
Total		19

Q15 Please explain why you consider that the Ross-MacDonald model, resulting in a focus on adult mosquitoes, was right. (Answered: 4 / Skipped: 19)

Q16 Please explain why you consider that the Ross-MacDonald model, resulting in a focus on adult mosquitoes, was not right. (Answered: 14 / Skipped: 9)

Q17 The WHO LSM manual of 2013 states that LSM is only recommended in places where larval breeding sites are 'few, fixed, and findable'. Do you agree? (Answered: 18 / Skipped: 5)

Answer Choices	Responses	n
YES	44.44%	8
NO	55.56%	10
Total		18

Q18 Why do you consider that LSM should only be recommended in places where larval breeding sites are 'few, fixed, and findable'? (Answered: 8 / Skipped: 15)

Q19 Why do you consider that LSM should not only be recommended in places where larval breeding sites are 'few, fixed, and findable'? (Answered: 10 / Skipped: 13)

Q20 Is larviciding a strategy that should be implemented without community engagement, like IRS, or would community engagement be possible? (Answered: 18 / Skipped: 5)

Answer Choices	Responses	n
Without community engagement	5.56%	1
With community engagement	94.44%	17
Total		18

Q21 Please explain why larviciding should be implemented without community engagement. Answered: 1 / Skipped: 22

Q22 Please explain why larviciding should be implemented with community engagement. Answered: 17 / Skipped: 6

Q23 Who should drive the adoption of larviciding in African countries? (more than one answer possible)
Answered: 18 / Skipped: 5

Answer Choices	Responses	n
Governments - MoH	94.44%	17
Governments - other Ministries (e.g. Works)	72.22%	13
NGO's	50.00%	9
Private sector	38.89%	7
Community groups	61.11%	11
Other (please specify)	27.78%	5
Total Respondents: 18		

Q24 What do you consider important hurdle(s) to move forward with larviciding? (more answers possible)
Answered: 18 / Skipped: 5

Answer Choices	Responses	
Operational complexity	66.67%	12
High cost	38.89%	7
Not sufficiently evidence-based	33.33%	6
Other (please specify)	33.33%	6
Terrain coverage and reconnaissance	27.78%	5
Mapping and GIS technology	27.78%	5
Application technology	22.22%	4
No effective and long-lasting larvicides	11.11%	2
Total Respondents: 18		

Q25 Would you consider larviciding as a single intervention feasible and appropriate? Or should it always be part of an integrated (IVM) package?
Answered: 18 / Skipped: 5

Answer Choices	Responses	n
Single intervention	0.00%	0
Integrated Vector Management	100.00%	18
Total		18

Q26 Please explain: (Answered: 18 / Skipped: 5)

Q27 If well organised and implemented, the impact of larviciding on malaria in sub-Saharan Africa can be substantial if not significant. (Answered: 18 / Skipped: 5)

Answer Choices	Responses	n
AGREE	94.44%	17
NOT AGREE	5.56%	1
Total		18

Q28 Please explain: (Answered: 18 / Skipped: 5)

Q29 Training of staff for larviciding should not be more difficult or complex than training staff for IRS. (Answered: 18 / Skipped: 5)

Answer Choices	Responses	n
AGREE	83.33%	15
NOT AGREE	16.67%	3
Total		18

Q30 Please explain: (Answered: 18 / Skipped: 5)

Q31 The application technology for larviciding (mist blowers, spraying equipment, etc.) is advanced enough to move forward with. (Answered: 18 / Skipped: 5)

Answer Choices	Responses	n
AGREE	72.22%	13
NOT AGREE	27.78%	5
Total		18

Q32 Please explain: (Answered: 18 / Skipped: 5)

Q33 We have a nice package of (biological) larvicides to move forward with. (Answered: 18 / Skipped: 5)

Answer Choices	Responses	n
AGREE	88.89%	16
NOT AGREE	11.11%	2
Total		18

Q34 Please explain: (Answered: 18 / Skipped: 5)

Q35 New long-lasting formulations of Bti and Bs have been tested recently (Afrane et al., Malar J. 2016: 577) and were shown to be efficacious for at least 3 months. The often-heard criticism that frequent re-treatment makes larviciding impractical therefore no longer seems valid. Do you agree? (Answered: 18 / Skipped: 5)

Answer Choices	Responses	n
YES	55.56%	10
NO	44.44%	8
Total		18

Q36 Please explain: (Answered: 18 / Skipped: 5)

Q37 Unless we move beyond the confines of the house, into the environment, we will not succeed with malaria elimination in Africa. (Answered: 18 / Skipped: 5)

Answer Choices	Responses	n
AGREE	83.33%	15
NOT AGREE	16.67%	3
Total		18

Q38 Please explain: (Answered: 18 / Skipped: 5)

Q39 Knowing where, when, and how often to use larviciding is more complex than knowing where, when, and how often to implement IRS. (Answered: 18 / Skipped: 5)

Answer Choices	Responses	n
AGREE	50.00%	9
NOT AGREE	50.00%	9
Total		18

Q40 Please explain: (Answered: 18 / Skipped: 5)

Q41 Would you consider larviciding equally important in both the dry and rainy season? (Answered: 18 / Skipped: 5)

Answer Choices	Responses	n
AGREE	66.67%	12
NOT AGREE	33.33%	6
Total		18

Q42 Please explain: (Answered: 18 / Skipped: 5)

Q43 Even in the rainy season, the minority of breeding sites produce the majority of vectors, so larviciding does make sense. (Answered: 18 / Skipped: 5)

Answer Choices	Responses	n
AGREE	61.11%	11
NOT AGREE	38.89%	7
Total		18

Q44 Please explain: (Answered: 18 / Skipped: 5)

Q45 Unless WHO alters its policy on LSM/larviciding there is little chance that it will expand significantly. (Answered: 18 / Skipped: 5)

Answer Choices	Responses	n
AGREE	66.67%	12
NOT AGREE	33.33%	6
Total		18

Q46 Please explain: (Answered: 18 / Skipped: 5)

Q47 Larviciding and malaria control policy in Africa (Answered: 18 / Skipped: 5)

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Total	Weighted Average
Policy barriers are more important than technological/operational barriers	11.11% 2	22.22% 4	16.67% 3	22.22% 4	27.78% 5	18	3.33
Vector control policy should be more closely linked to wider socioeconomic development	0.00% 0	5.56% 1	11.11% 2	50.00% 9	33.33% 6	18	4.11
We lack champions to drive larval control forward	0.00% 0	5.56% 1	22.22% 4	55.56% 10	16.67% 3	18	3.83
Larviciding should be undertaken by commercial vector control companies	11.11% 2	44.44% 8	22.22% 4	16.67% 3	5.56% 1	18	2.61
"We have enough evidence, let's get on with it"	5.56% 1	11.11% 2	11.11% 2	27.78% 5	44.44% 8	18	3.94

Q48 Are you a National Malaria Control Program (NMCP) manager or directly working in vector control for the NMCP?
Answered: 18 / Skipped: 5

Answer Choices	Responses	n
YES	22.22%	4
NO	77.78%	14
Total		18

Q49 20a. In which country do you reside and work within the NMCP? (Answered: 4 / Skipped: 19)

Q50 What vector control measures does your country currently apply in a programmatic manner (so not as part of research or a pilot project)? (more than one answer possible) (Answered: 4 / Skipped: 19)

Answer Choices	Responses	n
Indoor Residual Spraying (IRS)	50.00%	2
Insecticide-treated bednets (LLINs)	75.00%	3
House improvement (window screening, eave closure, etc.)	50.00%	2
Larval source management (breeding habitat removal or modification, larviciding, etc.)	75.00%	3
Other (please specify)	75.00%	3
Total Respondents: 4		

Q51 What do you consider the most compelling reasons to introduce or scale-up larviciding in your country? (Answered: 4 / Skipped: 19)

Q52 What do you consider the most important difficulties to introduce or scale up larviciding in your country? (Answered: 4 / Skipped: 19)

Q53 We appreciate the time you took to answer the questions of this survey. If you wish to provide some final comments or remarks, please write these below. (Answered: 17 / Skipped: 6)

Answer Choices	Responses	n
Comments/Remarks (optional):	64.71%	11
Your name (optional):	76.47%	13
Would you like to participate in additional surveys on this topic? (Yes/No)	94.12%	16

Appendix 3. Questionnaire and answers for 268 MalariaWorld and VCWG mailing list members.

Q1 Over the past 15 years, massive progress has been made in malaria vector control, primarily with two house-based interventions (Long-lasting Insecticidal Nets (LLINs) and Indoor Residual Spraying (IRS)). More than 6 million lives have been saved and some 700 million cases have been averted. In Africa overall, prevalence of P. falciparum in children 2-10 yrs of age has dropped from 33 to 16%. Is there a need for additional vector control tools besides LLINs and IRS? (Answered: 268 / Skipped: 0)

Answer Choices	Responses	n
YES	94.03%	252
NO	4.10%	11
DON'T KNOW	1.87%	5
Total		268

Q2 Do you know of countries that have eliminated malaria without some form of larval source management as an integral component of its elimination effort? (Answered: 261 / Skipped: 7)

Answer Choices	Responses	n
YES	7.28%	19
NO	92.72%	242
Total		261

Q3 Please mention the countries that have eliminated malaria without some form of larval source management as an integral component of its elimination effort here: (Answered: 20 / Skipped: 248)

Q4 Will malaria elimination in sub-Saharan countries require some form of area-wide control efforts directed at aquatic stages in order to succeed? (Answered: 257 / Skipped: 11)

Answer Choices	Responses	n
YES	69.65%	179
NO	8.17%	21
DON'T KNOW	22.18%	57
Total		257

Q5 Is there enough evidence that larviciding can be used in sub-Saharan Africa in a cost-efficient manner? (Answered: 257 / Skipped: 11)

Answer Choices	Responses	n
YES	29.96%	77
NO	33.85%	87
DON'T KNOW	36.19%	93
Total		257

Q6 Do you agree with the statement of the World Health Organization that larval source management is only recommended in places where larval breeding sites are 'few, fixed, and findable'? (Answered: 257 / Skipped: 11)

Answer Choices	Responses	n
YES	49.42%	127
NO	42.02%	108
DON'T KNOW	8.56%	22
Total		257

Q7 Is it a requirement that WHO alters its policy on LSM/larviciding for larviciding to expand significantly? (Answered: 252 / Skipped: 16)

Answer Choices	Responses	n
YES	59.13%	149
NO	20.63%	52
DON'T KNOW	20.24%	51
Total		252

Q8 Larviciding... (Answered: 246 / Skipped: 22)

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Total	Weighted Average
Is too expensive	9.76% 24	30.89% 76	30.89% 76	23.58% 58	4.88% 12	246	2.83
Is operationally complex	7.72% 19	27.24% 67	12.20% 30	36.59% 90	16.26% 40	246	3.26
Is only feasible in specific places	4.07% 10	17.07% 42	14.63% 36	48.37% 119	15.85% 39	246	3.55
Needs better (residual) larvicides	4.88% 12	11.79% 29	18.70% 46	44.31% 109	20.33% 50	246	3.63
Should be prioritized in malaria control	5.28% 13	14.63% 36	28.86% 71	32.52% 80	18.70% 46	246	3.45
Needs more evidence before broad adoption	4.88% 12	19.51% 48	16.67% 41	39.84% 98	19.11% 47	246	3.49

Q9 Who should drive the adoption of larviciding in African countries? (more than one answer possible)
(Answered: 242 / Skipped: 26)

Answer Choices	Responses	n
African governments	77.27%	187
Non governmental organisations	49.17%	119
Private sector	34.71%	84
Community groups	51.24%	124
Donors/funders	45.45%	110
Schools	22.73%	55
World Health Organization	61.57%	149
I do not believe in larviciding	4.55%	11
Don't' know	4.13%	10
Total Respondents: 242		

Q10 Is larviciding a strategy that should be implemented with or without community engagement?
(Answered: 242 / Skipped: 26)

Answer Choices	Responses	n
WITH COMMUNITY ENGAGEMENT	94.63%	229
WITHOUT COMMUNITY ENGAGEMENT	3.72%	9
DON'T KNOW	1.65%	4
Total		242

Q11 Do we need to move beyond the confines of the house, into the environment, in order to succeed with malaria elimination in Africa? (Answered: 242 / Skipped: 26)

Answer Choices	Responses	n
YES	90.08%	218
NO	4.13%	10
DON'T KNOW	5.79%	14
Total		242

Q12 Do you believe that, if well organized and implemented, the impact of larviciding on malaria in sub-Saharan Africa can be substantial if not (highly) significant? (Answered: 242 / Skipped: 26)

Answer Choices	Responses	n
YES	80.58%	195
NO	7.85%	19
DON'T KNOW	11.57%	28
Total		242

Q13 We appreciate the time you took to answer the questions of this survey. If you wish to provide some final comments or remarks, please write these below. (Answered: 178 / Skipped: 90)

Answer Choices	Responses	n
Comments/Remarks (optional):	53.93%	96
Your name (optional):	62.92%	112
Would you like to participate in additional surveys on this topic? (Yes/No)	91.57%	163