Cross case study analysis on malaria elimination: Synthesizing lessons from country experience

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ABBREVIATIONS

ABER: Annual blood examination rate
ACD: Active case detection or Proactive case detection
ACT: Artemisinin-based combination therapy
AIM: Action and Investment to Defeat Malaria
AL: Artemether-lumefantrine
AMC: Anti-Malaria Campaign (Sri Lanka)
ANE: USAID Bureau for Asia and the Near East
APCD: Activated Passive Case Detection (Sri Lanka)
API: annual parasite index
APMEN: Asia Pacific Malaria Elimination Network
AusAID: Australian Agency for International Development
BBIN: Bangladesh, Bhutan, India, and Nepal (regional initiative)
BHU: Basic Health Unit (Bhutan)
BTN: Bhutan
CPV: Cabo Verde
DDT: Dichlorodiphenyltrichloroethane
EIR: Entomological Inoculation Rate
GDP: Gross Domestic Product
GMEP: Global Malaria Eradication Programme
GNI: Gross National Income
GIS: Geographical information system
GPS: global positioning system
GTS: Global Technical Strategy
G6PD: glucose-6-phosphate dehydrogenase
ICRC: International Committee of the Red Cross
IDA: International Development Association of the World Bank
IDP: Internally displaced persons
IEC: Information, education and communication
IRS: indoor residual spraying
ITN: insecticide-treated net
IVM: Integrated vector management
KAP: Knowledge, Attitudes, and Practices
LKA: Sri Lanka
LKR: Sri Lanka Rupees
LLIN: Long-lasting insecticide-treated bed nets
LTTE: Liberation Tigers of the Tamil Eelam
MAP: Malaria Atlas Project
MDA: Mass Drug Administration
MERG: Malaria Evaluation Reference Group of the Roll Back Malaria Partnership
MIS: Malaria Indicator Survey
MOH: Medical Officers of Health (Sri Lanka)
MSF: Medecins Sans Frontieres

MUS: Mauritius
MYS: Malaysia
M&E: Monitoring and evaluation
NAM: Namibia
NGO: Non-governmental organization
ORC: Outreach clinic (Bhutan)
PCD: Passive case detection
PCR: Polymerase Chain Reaction
PHCV: Primary Health Care Volunteers (Malaysia)
PHL: Philippines
POR: prevention of re-introduction
RBM: Roll Back Malaria
RDHS: Regional Director of Health Services (Sri Lanka)
RDT: Rapid diagnostic tests
RMO: Regional Malaria Officer (Sri Lanka)
SES: Sanitary Epidemiological Service (Turkmenistan)
SOP: Standard Operating Procedure
SPR: Slide positivity rate
TEDHA: Tropical and Environmental Diseases and Health Associates
TKM: Turkmenistan
TKMI: Trans-Kunene Malaria Initiative (Angola and Namibia)
TUR: Turkey
UCSF: University of California, San Francisco
UNICEF: United Nations Children's Fund
USAID: United States Agency for International Development
USD: U.S. Dollar
USSR: Union of Soviet Socialist Republics
VDCP: Vector-borne Disease Control Programme (Bhutan)
WHO: World Health Organization
WHOLIS: World Health Organization Library
WHOSIS: WHO Statistical Information System

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SUMMARY

Malaria is transmitted by female Anopheles mosquitoes and is caused by parasites of the Plasmodium family. On a global level malaria morbidity and mortality has declined; from 2000 to 2015 the incidence rate of malaria is estimated to have decreased by 41%. With these reductions have come the call for malaria elimination in low transmission countries, which is defined as the reduction to zero of the incidence of infection caused by a specified agent in a defined geographical area as a result of deliberate efforts. Global eradication is also now on the agenda of the global malaria community. Eradication is defined as the permanent reduction to zero of the worldwide incidence of infections caused by the malaria parasite as a result of deliberate efforts.

The first attempt to eradicate malaria, the Global Malaria Eradication Programme (GMEP) (1955-1970), was discontinued after 1969 when eradication was no longer considered attainable with the funding, capacity and tools available. For most countries, elimination was no longer considered feasible and most programmes reverted to strategies for malaria control. Beginning in the early 1990s, however, action was taken to update control strategies and secure more funding for malaria control. Major gains in malaria control followed as initiatives and new tools brought new life to malaria control. By 2007, many countries were making steady progress in controlling malaria and this message of progress was elevated in October 2007 when the Bill & Melinda Gates Foundation announced the foundation’s goal to eradicate malaria. Malaria partners, including the World Health Organization, began to support efforts and strategies for elimination and eradication. Then, in 2015, a strategy to support global eradication was developed by the WHO Global Malaria Programme: the *Global Technical Strategy for Malaria 2016-2030* (GTS) was published.

While there is a tremendous amount of literature on malaria control and, more recently, malaria elimination, what was lacking is information on how malaria programmes have made progress or achieved elimination while others have not. Further, most research does not cover comprehensively the broad spectrum of strategies and activities employed by a national malaria programme, nor the technical, operational and financial aspects or enabling or challenging factors for malaria programmes.

In order to fill this gap, this thesis seeks to accomplish two aims. The first aim is to capture and review the experiences of national malaria programmes that have a goal of malaria elimination or have achieved elimination and identify successes and challenges. The second aim is to compare and synthesize experiences from multiple malaria elimination programmes across systems and cultures in order to distill key determinants, success factors and remaining challenges.

For the first aim, methods were developed to collect and review information from the Bhutan and Sri Lanka malaria programmes, which were seeking to eliminate malaria at the time of analysis. The case study methodology was chosen as the best way to comprehensively capture the experience of malaria programmes. It uses a mixed method approach, which included a

desk review, in-country document review, quantitative data extraction, key informant interviews, and analysis.

Sri Lanka has successfully eliminated malaria, as of September 2016 when the WHO certified the country as malaria-free. Sri Lanka reported zero indigenous cases since October 2012. A major challenging factor in the country was the nearly 30 years of civil conflict, which affected the most malarious areas of the country, the north and east. A second major challenging factor is the proportion of *P. vivax* infections, which rose as cases decreased. A previous attempt to eliminate malaria in the country occurred in the 1960s, after implementing IRS with DDT.

Bhutan has made major progress towards malaria elimination since 2000. Malaria transmission in Bhutan has mainly occurred in the southern, low-lying region bordering the Indian states of Assam and West Bengal. Transmission occurs throughout the year in this region. Malaria importation in the southern part of the country is a major challenge for elimination in Bhutan.

For the second objective, a cross case-study methodology was employed. This method compared the experiences of malaria programmes documented in the existing case-study reports (long report form) under two important themes, vector control and programme management. Methods for the cross-case analysis included development of a conceptual framework, qualitative data extraction, conduct of a workshop to review data extraction and key learnings, and analysis. These analyses included nine countries in the UCSF-WHO GMP Eliminating Malaria Case-Study Series (Bhutan, Cape Verde, Malaysia, Mauritius, Namibia, Philippines, Sri Lanka, Turkey, Turkmenistan).

The results of this body of work align closely with the overarching global framework of the WHO Global Technical Strategy (2016-2030). Strong malaria elimination programmes focused on their surveillance and response interventions, ensuring case-based surveillance was in place with identification, classification, follow up and response on an individual case basis. Entomological surveillance was an important part of this surveillance system – the vector control programme must have sufficient capacity and technical skills. Case management is also an important component of surveillance systems, in that programmes must ensure timely access to quality diagnosis and treatment services, and reporting must be timely and accurate. Human resources must be sufficient, which is often a challenge in the periphery. The strongest malaria programmes crafted evidence-based strategies when they were able to access and use quality data, so use of data plays a strong role in decision-making on strategies and intervention choice. However, across the case-studies it was found that programmes did not sufficiently link parasitological and entomological surveillance data, nor was it documented clearly how prevention interventions were monitored to ensure they were targeting the most at risk, and evaluated on effectiveness in the field. This research did show though that highly flexible programmes have the ability to adapt to changing conditions, using data to develop strategies and target interventions in response to the current conditions. This flexibility in turn requires human resource capacity and technical skills.

The results of this work also indicate the requirement of robust leadership of malaria programmes, and an element of verticality that ensures accountability and action to reach elimination goals. Motivation and incentivization are key to ensuring programme operations, and there is a crucial need to identify the best methods to maintain a high level of motivation and work quality. Not surprisingly political and financial commitment to the elimination goal are major enabling factors for malaria programme success. As malaria incidence decreases, access to financial and human resources will likely decrease as attention shifts to other higher priority vector-borne diseases. Considering the risk of declining resources and commitment, and the existing needs in surveillance, programmatic tools and quality of interventions, the gains made since 2000 to current day are fragile. Vigilance as well as commitment and financial support must be maintained for malaria programmes in order to reach elimination and eventual global eradication.

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CHAPTER 1

Background and Introduction

1.1 Global burden of malaria and its causes

On a global level malaria morbidity and mortality has experienced major declines. From 2000 to 2015, the incidence rate of malaria was estimated to have decreased by 41% [1]. Between 2010 and 2015, it was estimated to have declined 21% [1]. Forty of the 90 countries and territories considered to have malaria transmission were estimated to have a reduction in malaria incidence rate of 40% or more [1]. In 2015, the majority of malaria cases (90%) occurred in the WHO African Region, followed by South-East Asia (7%) and Eastern Mediterranean (2%) [1].

Malaria is transmitted by female Anopheles mosquitoes and is caused by parasites of the Plasmodium family. There are four malaria species that can be transmitted via the vector from one human to another (*Plasmodium falciparum*, *malariae*, *ovale*, *vivax*) and one species (*P. knowlesi*) that is spread from macaque monkeys to other monkeys and is also known to infect humans (zoonotic transmission) [1, 2]. *P. falciparum* and *P. vivax* infections are the most prevalent [2]. *P. falciparum* infections account for the largest number of deaths from malaria [1, 3]. *P. vivax,* although at one time considered benign, causes a substantial burden of morbidity [3, 4]. *P. vivax* has a wider distribution than *P. falciparum*, with nearly 40% of the population of the world at risk of *P. vivax* [3]. Furthermore, *P. vivax* has a dormant liver stage, called the hypnozoite stage, which may extend the lifespan of the parasite [5]. Hypnozoites are difficult to detect and treat, requiring 14 days of treatment with primaquine. Primaquine can cause hemolysis in patients with glucose-6-phosphate dehydrogenase (G6PD) deficiency, the most prevalent inherited enzyme deficiency in the world [6]. It is easier to detect *P. falciparum* infections than *P. vivax* infections. For any given disease state the density of parasites found in a patient's blood will be lower in *P. vivax* than *P. falciparum* infections. In addition, the detection of those parasites even with modern diagnostics is harder. Rapid diagnostic tests (RDTs) have a higher sensitivity for *P. falciparum* compared with those available for *P. vivax* infections [5]. Thus *P. vivax* is more difficult to diagnose (more difficult to find the parasites) and treat (the hypnozoite parasite stage is difficult to treat). The Asia Pacific region accounts for 90% of the global risk of *P. vivax* infection, surpassing the Americas and Central Asia [7]. Not surprisingly, both Bhutan and Sri Lanka – the subject of part of this thesis – have had a significant portion of their malaria burden caused by *P. vivax* parasites.

Approximately 400 Anopheles species (females only) transmit malaria while only 30 are considered vectors of major importance [1]. The Asia Pacific region is of particular note because of its high diversity of Anopheles species and species complexes that are vectors for human malaria [8]. Malaria transmission is determined by several factors, including importantly the presence of vectors that transmit malaria and their vectorial capacity. Vectorial capacity is the number of new infections the population of a given vector would distribute per case per day at a given place in time, assuming conditions of non-immunity [5]. Receptivity is another measure of the risk of malaria transmission which takes into account the climate, local ecology, human and vector behavior, human population size, and vector longevity in relation to the period of sporogony.

1.2 Malaria elimination and eradication

Malaria elimination is defined as the reduction to zero of the incidence of infection caused by a specified agent in a defined geographical area as a result of deliberate efforts [5]. Global eradication of malaria means the permanent reduction to zero of the worldwide incidence of infections caused by the malaria parasite as a result of deliverable efforts [5]. The first eradication attempt was made as part of the Global Malaria Eradication Programme, or the GMEP, which was in place from 1955 to 1970. The GMEP targeted elimination in countries with low or intermediate malaria intensity, and was successful in removing risk of malaria for approximately one billion people, but was not successful in reaching the goal of eradication of malaria worldwide [9]. The GMEP ended due to a reduction in funding and political commitment in part blamed on poor leadership, weak management, and poor systems and logistics [9]. Some technical issues had arisen during the GMEP, such as vector resistance to DDT, the most frequently used insecticide, and parasite resistance to chloroquine, the most frequently used antimalarial drug.

The GMEP was launched in 1955 at the World Health Assembly after postwar malaria epidemics in southern Europe were successfully controlled using indoor residual spraying (IRS) using the new insecticide DDT and new antimalarial treatments such as chloroquine. Both tools were developed towards the end of World War II [9]. The GMEP primarily depended on IRS with DDT with geographies in the Americas, Europe, Mediterranean, western and eastern Asia, and western Pacific and Australia targeted for elimination [9]. The elimination programmes in country were developed as vertical, time-bound programmes that implemented vector control and parasitological surveillance, diagnosis and treatment [9]. Approximately 68 countries eliminated malaria during roughly the years of the GMEP [9].

After the GMEP most countries that had not successfully eliminated malaria transitioned to a programme of malaria control. Elimination was no longer an accepted goal for countries and eradication was not considered possible anymore. Then, following a period of resource mobilization and control efforts beginning in the early 2000s, in part due to the establishment of the Global Fund to Fight AIDS, Tuberculosis and Malaria, the eradication goal and elimination country by country re-emerged as part of the global development vernacular. The declaration of malaria eradication as the goal for malaria control at the Malaria Forum in October 2007 (convened by the Bill & Melinda Gates Foundation) re-established eradication and elimination as feasible goals. The World Health Organization (WHO) and Roll Back Malaria Partnership (RBM) also began to support this notion [10]. In 2015, the global framework to support global eradication and set out the pillars required to achieve this goal were developed. The WHO Global Malaria Programme developed the *Global Technical Strategy for Malaria 2016-2030* (GTS) as the strategy to achieve global malaria eradication. RBM launched the investment and policy framework through the *Action and Investment to Defeat Malaria 2016-2030* (AIM). The goals were further clarified through and the publishing of *Aspiration to Action*, developed by Bill Gates and the UN Secretary-General's Special Envoy, Ray Chambers [2, 11, 12]. Lastly, the research and development gaps and an agenda for future planning was elucidated by MalERA in 2011, and updated in 2016 [13, 14]. A global goal of malaria eradication by an end date of 2040 has been proposed, and the GTS lists 35 countries targeted to achieve elimination by 2030. Elimination is firmly embedded now in the malaria global discussions and consciousness, and the eradication goal continues to be debated.

While support for national elimination and global eradication has resurfaced, there remain major challenges to the achievement of national, regional and global goals. Technical, operational and financial challenges will impact different countries in different ways.

The technical challenge for most countries is adapting tools, strategy and operations to the changing epidemiology of malaria. Most eliminating countries have experienced major changes to their contexts, including a change in demographics where most infections occur in adult males, an increase in population mobility and migration, a greater proportion of infections are caused by *P. vivax*, and asymptomatic infections may go undetected and fuel transmission.

The populations most affected by malaria have shifted in many low burden countries from children under five years of age and pregnant women to adult males [15]. Adult males tend to have an increased risk of malaria through their occupational and social habits that put them in contact with the vectors in their particular habitats at their biting times. Some areas also have a high degree of population migration and mobility, in general marked by populations of mainly adult males. The mobility and migration across the Greater Mekong Subregion in the Asia Pacific Region contributes to the growing resistance to artemisinin antimalarial therapies in *P. falciparum* infections, which threatens progress towards elimination and eventual eradication [2]. The Greater Mekong Subregion is considered the epicenter of artemisinin drug resistance, with resistance detected along the Thailand-Myanmar, Thailand-Cambodia, Vietnam-Cambodia, and Vietnam-Laos borders [16, 17]. Artemisinin resistance may be spread because of population movement as undiagnosed and untreated infections move and transmit malaria in new locations, and can also occur de-novo, which means the formation and multiplication of a mutant malaria parasite (along with the necessary generation of needed densities of gametocytes for onward transmission) [18]. The identification of the K13 molecular marker of artemisinin resistance has helped to monitor and track the location and spread of resistance [19].

A further challenge to malaria case management is presented by *P. vivax* malaria, which is more difficult to diagnose and treat than *P. falciparum* because of the dormant liver stage (hypnozoites) of the parasite [3]. Elimination in many countries may be challenged by the presence of hidden reservoirs of infection [20]. These reservoirs contain infections that are mostly asymptomatic, meaning that people will not seek diagnosis and treatment and inadvertently fuel malaria transmission [2]. Efficient and cost-effective surveillance tools are needed to quickly identify all infections, including asymptomatic ones, in order to ensure prompt treatment and halting the transmission cycle.

A further technical challenge, one that is particular to the Asia Pacific Region, is the diversity of malaria-transmitting vectors and the development of outdoor-biting behavior. Traditional vector control methods of IRS and ITNs/LLINs do not target the malaria vectors that bite humans outside and new tools to reduce vector densities and protect populations are needed [2, 8].

There are major operational challenges to achieving malaria elimination. Weak national health systems and malaria programmes in eliminating countries have led to suboptimal diagnosis and treatment, weak surveillance systems and supply chain problems [2]. An unregulated private sector in some countries may slow progress by providing low quality diagnosis and treatment [2]. Capacity in national malaria programmes for parasitological and entomological surveillance and vector control must be bolstered. Monitoring and evaluation (M&E) of malaria control and elimination interventions with precise measurement of impact and cost-effectiveness is needed. In many cases, malaria programme personnel do not have adequate programme management skills and experience to ensure quality implementation and monitoring [2].

A further challenge for eliminating countries is the need for adequate and sustained financing, which is affected by low political commitment for elimination. Long term political and funding commitments are essential for countries to move through and sustain elimination [2].

1.3 Malaria elimination strategies and interventions

1.3.1 Case management

Prompt and appropriate diagnosis and treatment of malaria is the basis for sound case management. In eliminating countries (as is the case for control countries), the majority of infections will be diagnosed and treated in health facilities through passive case detection. Passive case detection occurs when an infected person has symptoms and presents at a health facility for care. In an elimination setting, the key challenge is maintaining awareness and skills of health workers to detect malaria infections, as their skills and vigilance appears to decline as malaria cases become few and far between. This process must include mandatory reporting of malaria cases.

Case confirmation must be done by a reference laboratory. Elimination will require more sensitive diagnostics than the traditional tools of microscopy and RDTs because of the larger number of infections that are low density infections (fewer parasites per microliter) thus more difficult to confirm [10, 15, 21]. In addition the current RDTs have suboptimal sensitivity to detect *P. vivax* infections, which in many countries will become the larger proportion of infections as cases decrease [3, 21]. Elimination programmes will require field-friendly molecular diagnosis tests to identify all infected individuals, such as Polymerase Chain Reaction (PCR) or LAMP, which are more sensitive than microscopy or RDTs [21, 22]. PCR is becoming more commonly used in elimination settings. Parasite genotyping may help programmes differentiate between local and imported infections, helping them to identify the source of imported infections, and may also show connections between cases such as transmission that stems from an imported case [22, 23]. Serology detects antimalarial antibodies so it cannot be used to identify current infection [24].

Malaria treatment must eliminate all parasites, or radical cure for *P. vivax* infections, which would include eliminating hypnozoites in the liver [3, 10]. Hypnozoites are the dormant parasite form in the liver that can lead to a relapse in infection, from months to even years after the primary infection, without the presence of vectors [4]. Primaquine is currently the only antimalarial that will treat the hypnozoite stage, but countries with populations with G6PD deficiency may require a point of care test to identify enzyme-deficient patients before issuing primaquine, and this test is not yet widely used [2]. Primaquine in a low-dose format is also needed for *P. falciparum* infections to eliminate mature stage IV and V gametocytes, which are the parasite stages that are passed on to the vector, resulting in transmission. All antimalarial medicines must be monitored for safety and efficacy, and antimalarial drug resistance must be monitored [2]. Resistance to artemisinin necessitates a priority for elimination of *P. falciparum* in the GMS [2].

The malaria vaccine closest to being available, RTS,S had, within the first six months, an efficacy of 70% and is likely to reduce morbidity and mortality from *P. falciparum* in children in high-endemic settings [13]. In the future the vaccine may become a complementary tool that could work alongside another strategy, such as MDA, in elimination settings [2]. Non-immune travelers and migrants should be issued chemoprophylaxis or targeted for control measures to protect them from infection [2].

1.3.2 Surveillance and response

As countries move toward elimination, surveillance systems shift from measuring morbidity and mortality to identifying every infection, including those with symptoms and those without, and measuring the level of transmission in order to guide programme response [13]. Surveillance is thus considered an over-arching intervention, with the capacity to identify cases, support decisions about what to do in response to cases, and guide response and monitoring to ensure success of the malaria programme.

Recent evidence suggests that in low transmission areas, sub-microscopic malaria infections may be the source of 20-50% of malaria transmission [21]. Sub-microscopic infections are not detected by microscopy or RDT because of the low density of parasites, but they would be detected by PCR. Sub-microscopic infections can last months or even years and may be asymptomatic, meaning that they are not accompanied by fever or other acute symptoms [20]. Most malaria programmes focus on early detection of infection that tend to be symptomatic. For elimination, programmes must also reach low-density, chronic infections that may not have symptoms. While some of the surveillance tools described below may reach these types of infections, Mass Drug Administration (MDA) with concomitant vector control should also be explored. MDA is defined as “the use of drugs to treat whole populations for malaria, irrespective of, and without knowledge of, who is infected” [13]. Targeted or focal MDA may be a strategy effective for some countries to accelerate elimination [13, 25]. There are gaps in the evidence for MDA regarding the regimen to use, ideal size of target population, timing, what combination of interventions to use alongside it, and how to handle population mobility and importation [25].

Passive case detection will continue to play a role in elimination settings and should be maintained, but will not identify all infections and other modes of surveillance must be used [2].

Active case detection and case investigation is important to clearing all infections and transmission foci. Active case detection is defined as “the detection by health workers of malaria infections at community and household level in population groups that are considered to be at high risk.” Active case detection may take the form of a fever screening followed by testing of all febrile patients or testing of a target population without fever screening [26].

Reactive Case Detection, or RACD, occurs in response and nearby the household or origin of infection of an index case. Reactive case detection is used to find other infections as infections tend to cluster spatially and temporally [24]. RACD should only be conducted in areas that are receptive to malaria transmission, but can be conducted in reaction to either an imported or a local index case, given that both types of cases can lead to secondary transmission. There is lack of evidence to support RACD as an intervention [24]. Therefore, if it is to be used, it should be as part of a focus investigation that also includes vector control [24].

Proactive case detection is used by many programmes to screen high-risk populations for malaria infection, and is likely to be most effective in bringing down transmission in areas with seasonal transmission, a circumscribed and non-mobile population, and one amenable to screening procedures [22]. It may also be most useful in areas with moderate to low transmission, as opposed to low transmission [24]. When diagnostic tools are able to detect most infections, research indicates that PACD may reduce transmission in lower prevalence settings [24]. Screening of mobile populations or border screening is one form of proactive case detection. However, border screening along land borders that are long and poorly monitored, and where many migrants take routes across other, informal border crossings, make border screening a less effective option [22, 24]. To target mobile populations, programmes can instead use travel history data from health facilities and border surveys in GIS systems to identify importation risk and design appropriate strategies. Social networking methods can be used to identify and provide services for mobile groups at higher risk for malaria infection [27]. These methods may be efficient because imported cases are likely connected to a wider social group that may be at similar risk for malaria. In general, PACD is best suited for moderate to low transmission areas and should be conducted during the driest season when infections are most clustered [24].

Other ways to target imported infections include: improving access to healthcare for mobile and migrant populations, providing IEC about malaria prevention and distribution of personal protection, reducing receptivity, facilitating partnerships across borders, public private partnerships (e.g., working with mining companies to conduct malaria prevention or surveillance activities), at-source testing and treating (e.g., requiring testing pre-arrival in destination country), or using diagnosis screening incentives [23].

Surveillance systems must include a malaria-specific reporting system in order to collect and analyse the additional information that is needed to target interventions and measure their impact [2]. Instead of periodic reporting of aggregated case data, rapid and real-time reporting of individual confirmed cases by both public and private facilities is necessary [2, 28]. The WHO recommends that all cases are reported to district and national malaria control teams immediately [26]. The 1-3-7 approach used in China provides an country programme example of well-defined targets for guiding and monitoring case reporting (malaria cases to be reported within one day), investigation (case confirmation and investigation within three days) and response (surveillance and vector control response within seven days) [29]. After reporting, an important step is mapping of malaria cases to further guide intervention choice and coverage [13].

Data collection must include disaggregated information on each case and a case investigation for every case to determine the origin of the case, to make the determination whether it is imported or local. This is typically done through documenting the travel history of the positive case, although countries need to standardize methods and ask the travel history beyond 4-6 weeks for *P. falciparum* and even longer for *P. vivax* because the infection could have originated before that point [23]. The system should include a measurement of compliance and completeness [28].

Programmes need computer-based data storage and management systems, and an online elimination database that is manageable by the NMCP, with automated systems for analysis and outputs that will quickly identify outbreaks and guide responses [28]. Outputs of the system must be tailored for each level so that the most useful information is provided, and feedback down to the community level is essential [28]. Analysis of the surveillance system data identifies areas of risk and where to target interventions. This analysis must rapidly assess trends over time and place [13], and have an outbreak prediction and response component. The risk of importation (vulnerability) and transmission potential (receptivity) must also be monitored [2].

Analysis of data collected and maintained in the surveillance system should be used to best allocate resources to populations and areas or foci most in need [2]. Elimination necessitates a shift from universal coverage of interventions, or a goal of 100% population coverage, to targeting of vector control in foci that are still active or recently active [2].

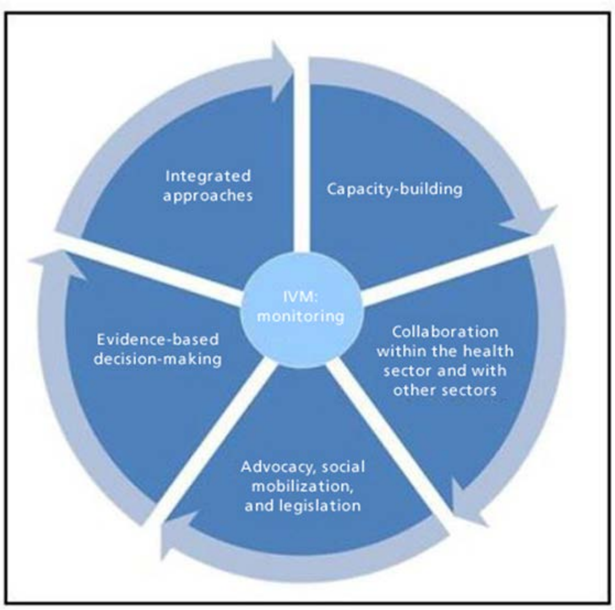
In an ideal scenario, national, regional and global surveillance systems would be linked and real-time data about outbreaks and areas of transmission would be identified and targeted with interventions [28]. Real-time sharing of case information, outbreaks and response strategies across international borders is needed for elimination [28]. These communications would encourage cooperation and allow for faster outbreak forecasting and response.

Targeted responses to a case may include: active case detection activities, monitoring of quality and coverage of ITN and IRS and other vector control activities, focal MDA, and education on prevention and response strategies to malaria cases at the community level [28]. The district level responds to a case with supervision, coordination, supply and intervention decision-making [28]. The national level response is decision-making on the appropriate outbreak response and how the data will influence and guide the national elimination strategy [28].

1.3.3 Entomological surveillance and vector control

The vector control goal in the context of malaria control and elimination is to reduce vectorial capacity of local vector populations, which depends on human biting habits, density, longevity, and period of sporogony. For elimination, the malaria reproductive rate, which is the expected number of human cases that arise from each human case in a population, must be reduced to less than 1 [13]. Elimination strategy is based upon surveillance and response. An integral part of the response in elimination is to focus vector control interventions to the areas of highest risk in order to reduce vectorial capacity and achieve the required malaria reproductive rate. This assessment is done through analysis of epidemiological and entomological monitoring and surveillance to understand transmission potential and insecticide resistance levels [22]. Integrated Vector Management is an overarching vector control strategy for all countries, and includes the components described in Figure 1.1, below [30].

Figure 1.1: IVM framework and distinguishing characteristics. Source: Beier et al. [30]



Elimination programmes must have regular entomological monitoring systems in place to keep vector information (bionomics, behavior) updated and monitor vector susceptibility to insecticides [2]. This is the case for areas with ongoing or with interrupted transmission. Routine monitoring of intervention coverage is also important, to identify and rectify gaps in coverage and to ensure that the most effective tools are used to reduce transmission [2]. Management tools to reduce risk of insecticide resistance may be necessary, such as spatial and temporal insecticide rotation, which entails rotating insecticides with different modes of action by location (e.g., in different districts over time) for IRS campaigns or through combining multiple interventions [2, 31].

Broadly applied vector control interventions are ITNs/LLINs and IRS [2]. Supplementary methods are also appropriate, such as larval source management, which can be larviciding or larval control [2]. However, in many low endemic areas, there is a need to implement vector control tools for early or outdoor-biting and outdoor-resting vectors that are not susceptible to these traditional tools [2, 10].

Self-protection measures must be considered, to protect populations that may increase the chance of malaria importation to an elimination area. Chemoprophylaxis, ITNs or, for more mobile population groups, insecticide-treated hammocks for individuals traveling to higher endemic settings, can help prevent onward transmission [23]. Some of these measures are not best suited for populations that are not well defined or characterized. Reducing receptivity in areas where high risk individuals reside is another strategy, and may involve working with private companies or other ministries that monitor development projects that may recruit these population groups [23].

1.3.4 Programme management

In addition to the parasitological and entomological surveillance, response, and vector control interventions that are used for elimination, there are aspects of programme management which must be addressed in order for programmes to achieve and sustain elimination. As described in the 2016 WHO *Global Technical Strategy*, health system performance is key, as it will affect the quality of surveillance, diagnosis and treatment tools and interventions, management of supply chains, regulation of the private sector, and the technical and human resource capacity to do the on-the-ground work of elimination [2].

Malaria programmes operate in environments of varying degrees of decentralization and integration of the malaria control programme into the general health services. They also operate in a context of either strong or weak political and financial commitment for elimination. These background factors influence the amount of programme resources dedicated to malaria control and elimination (e.g., financial and human resources), implementation, and accountability for meeting malaria elimination goals.

Development of national strategic plans that take into account updated epidemiology and heterogeneity of malaria allows for monitoring of implementation at regular intervals, and identify of programmatic, technical and efficiency gaps [2]. Quality implementation of strategic plans depends upon a strong base of health workers and malaria experts [2, 31]. Training in epidemiology, evidence-based decision making and programme management components, such as M&E and supervision and management skills, are needed by programmes to ensure high quality implementation and monitoring. Work force motivation must be addressed in a context of long term elimination goals, and training and supervision must be enhanced for the goal of high quality implementation and coverage to be maintained.

Collaborations will be key for elimination. Cross border and regional collaboration for elimination can reduce importation risk across countries by sharing data, evidence and best practices and align strategies and interventions to achieve a higher quality of implementation [2, 22]. Multisectoral collaboration with other ministries, regulatory authorities, private sector and NGOs will also play a strong role [2].

1.4 Overview of Malaria in Sri Lanka and Bhutan

1.4.1 Malaria in Sri Lanka

Sri Lanka nearly eliminated malaria in the 1960s, after implementing IRS with DDT. The island had previously had highly endemic malaria transmission focused in the northern and eastern regions. It was one of the first countries to roll out IRS (1945) with DDT and to join the Global Malaria Eradication Programme (1955-1970). After malaria transmission was reduced, the programme scaled down IRS and surveillance and response activities while there was a reduction in financial resources. As a result of this relaxation of programme efforts, in combination with a reduction of rainfall in the wet zone, there was a massive resurgence of malaria in 1967-1968. In the next year, IRS was scaled back up but the programme was never able to achieve the low incidence reported in the 1960s until recently.

The primary vector in Sri Lanka is *Anopheles culicifacies*, a species that breeds in river and stream pools. Malaria transmission tends to increase when there are monsoon rain events in the dry zone, or when the monsoon rains are weaker or do not occur in the intermediate climate zone. Both *P. falciparum* and *P. vivax* infections occurred in Sri Lanka, with limited *P. malariae* and *P. ovale* infections. The proportion of infections due to *P. vivax* increased over the years and was 90.3% of all infections in 2011. Major at risk populations included male gem miners, male military personnel, and people living along streams and rivers with recorded high vector density and mobile populations.

Sri Lanka has faced several challenges to controlling and eliminating malaria. A nearly 30-year civil war between the Liberation Tigers of the Tamil Eelam (LTTE) and the Sri Lankan Government (1983 to 2009) disrupted malaria control in areas where malaria transmission has historically been the highest (the north and east of the country). The high proportion of *P. vivax* infections has led to a greater difficulty in diagnosis and treatment.

Enabling factors for Sri Lanka’s goal of malaria elimination included sustainable funding of the malaria programme, especially since the beginning of the Global Fund malaria grants, flexibility in programme approach, and strong parasitological and entomological surveillance and vector control strategies and programmes.

Since October 2012, Sri Lanka has reported zero indigenous malaria cases. In September 2016, the WHO certified Sri Lanka as malaria-free [32].

1.4.2 Malaria in Bhutan

Bhutan has made major progress towards malaria elimination since 2000, and the country has a goal to eliminate all malaria by 2016.

Malaria transmission in Bhutan has mainly occurred in the southern, low-lying region bordering the Indian states of Assam and West Bengal. Transmission occurs throughout the year in this region. Seasonal transmission occurred in the middle of the country, which runs roughly in a band from east to west. The north-east and central part of the country is not considered malaria-receptive because of the high elevation and cooler temperatures. Malaria transmission mainly occurs in Bhutan from April to September, which is considered the warm monsoon period. Malaria cases tend to peak in April and again in August-September (at the beginning and end of the monsoon period). The highest peak is in August-September. Since 2010, malaria infections in Bhutan were mainly *P. vivax* (nearly 60% of infections in 2010) with some *P. falciparum* and mixed infections. At-risk populations in Bhutan include male farmers and students between the ages of 15-49. Imported infections are an important factor for transmission in Bhutan. Important malaria-transmitting vectors in Bhutan were considered *Anopheles pseudowillmori* and *Anopheles culicifacies*. They are both endo- and exo-phagic and anthropophilic and are relatively abundant during the peak transmission season. However current studies have failed to incriminate vectors in the country.

Challenges for Bhutan's Vector-Borne Disease Control Programme have included the difficult terrain, which has led to landslides and impassible roads in the monsoon months as well as a low-lying region in the south that borders India and is high-risk for malaria transmission. There is significant population movement along this southern border with India. In addition there are migrant workers that enter Bhutan to work on the large-scale development projects (eg, dam and airport construction).

Recent records indicate that Bhutan is on the path towards elimination by the end of 2016. There were only 45 confirmed cases in 2013.

1.5 Rationale for PhD thesis

Malaria is a complex disease. Its transmission relies upon both a human and vector transmission cycle and human-vector interaction. Malaria transmitting vectors and *Plasmodium* parasites have adapted to survive and thrive in disparate contexts. Eliminating malaria is a daunting task. It is not surprising that many countries have experienced a high level of transmission and have major challenges in reducing burden, let alone achieving elimination. However there are other countries that have made good progress and are close to achieving zero indigenous cases, or have done so already. Why are some malaria control programmes able to achieve malaria elimination? What are the success factors?

While there is a tremendous amount of literature on malaria control and, more recently, malaria elimination, what is lacking is information on how certain malaria programmes have made progress or achieved elimination and others have not. Further, most research does not cover comprehensively the broad spectrum of strategies and activities employed by a national malaria programme, nor the technical, operational and financial aspects. Gaps in knowledge about country experience include the important strategies in the areas of surveillance and response; vector control, including entomological surveillance; programme management and decision making; and diagnosis and treatment. Financial aspects include the cost of malaria control, malaria elimination and prevention of reintroduction. Enabling or challenging factors also required exploration, such as the level of funding from domestic and external sources, participation in regional and global forums, and the level of political support in the country.

In order to fill this gap, this research and thesis seeks to accomplish two aims. The first aim is to capture and review the experiences of national malaria programmes that have a goal of malaria elimination or have achieved elimination and identify successes and challenges. The second aim is to compare and synthesize experiences from multiple malaria elimination programmes across systems and cultures in order to distill key determinants, success factors and remaining challenges.

For the first aim, methods were developed and employed to collect and review information from the Bhutan and Sri Lanka malaria programmes, which were seeking to eliminate malaria. Study methods considered for this task included the case-study methodology, WHO Malaria Programme Reviews (WHO), observational research studies, and situation analyses. The case-study method was chosen as the best way to comprehensively capture the experience of malaria programmes. It uses a mixed method approach, applying both quantitative and qualitative data collection and analysis.

For the second objective, a cross case-study methodology was employed. This method compared the experiences of malaria programmes documented in the existing case-study reports (in long report form) under two important themes, vector control and programme management.

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CHAPTER 2

Aims and Objectives

2.1 General Aims

The overall aim of this PhD thesis is to learn through historic analysis of countries who have pursued malaria elimination, both successfully and unsuccessfully, what key strategies and approaches other malaria elimination programmes can or should adopt. The first approach taken to address this aim was to characterize two malaria elimination programmes, Sri Lanka and Bhutan, and identify programmatic strengths that have contributed to their successful malaria control programmes. The second approach was to analyze across a series of malaria elimination programmes their successes and challenges with regard to two important technical topics for the achievement of malaria elimination: vector control and programme management.

2.2 Specific Objectives

A. To characterize the Sri Lanka malaria elimination programme through a description of the experience of the national malaria programme and the lessons learned by the programme as it has transitioned into elimination. The study also seeks to understand the shift in cost of malaria control per capita at risk as a country moves from high endemicity to controlled, low-endemic malaria. The hope is that other countries will benefit from the experiences of Sri Lanka (reported in paper 1, Chapter 3)

- Identify and describe in detail the key strengths and weaknesses of the malaria control and elimination programme
- Explore the main challenges for Sri Lanka to achieve elimination
- Calculate and compare the cost of malaria control and elimination in Sri Lanka during high, low and nearly zero transmission periods

B. To characterize the malaria programme of Bhutan from 2000 to 2010, by exploring trends in the malaria epidemiology, control strategies, interventions, and enabling and challenging context of Bhutan, with emphasis on the southern border and population migration (reported in paper 2, Chapter 4).

- Identify and describe in detail the key strengths and weaknesses of the malaria control and elimination programme
- Explore the main challenges for successful elimination in Bhutan, with particular regard to importation of malaria along the southern border

C. To review key components of malaria programme vector control strategies and interventions to identify success factors along the road to elimination, focusing on vector control tools,

approaches, coverage and impact in elimination settings of Bhutan, Cape Verde, Malaysia, Mauritius, Namibia, Philippines, Sri Lanka, Tunisia and Turkmenistan (paper 3, Chapter 5).
- Distill the key determinants of programmatic success in the area of entomology, entomological surveillance and vector control in malaria eliminating countries
- Explore in detail the key entomological and vector control challenges to successful and sustained elimination in malaria eliminating countries

D. To review programme management strategies and contexts across nine malaria programmes operating in different socio-economic, political and ecological contexts to identify success factors along the road to elimination (paper 4, Chapter 6). The malaria programmes of Bhutan, Cape Verde, Malaysia, Mauritius, Namibia, Philippines, Sri Lanka, Tunisia and Turkmenistan were the subject of the analysis.
- Distill the key determinants of programmatic success in the area of programme management in malaria eliminating countries, with a focus on implementation quality, strategy building, resource requirements, and enabling factors
- Explore in detail the key challenges to successful and sustained elimination in malaria eliminating countries in the management of a malaria control programme and possible areas of action

2.3 Study Sites

Sri Lanka

Literature searches and document review occurred from September to December 2009 in San Francisco. Data collection in Sri Lanka occurred from December 2009 to March 2010, with follow up from San Francisco through December 2010.

Data collection mostly focused on the years 1995 to 2011. Information was collected on the pre-1995 malaria programme strategies and activities, mainly from document review. While the scope of the data collection centered on the national Anti-Malaria Campaign, based in Colombo, data collection also occurred in three districts (Ampara, Anuradhapura and Kurunegala) to identify programme implementation and strategies occurring sub-nationally, and to collect information on malaria programme costs that only is available at the district level. These three districts were purposively chosen as the represent different epidemiological contexts, level of experience of the malaria programme regional officers, and were considered safe for the researcher to travel to at the time of the study. All districts received funding from the Global Fund to Fight AIDS, Tuberculosis and Malaria (Global Fund), but during different grant rounds. Ampara was previously part of the conflict zone and Anuradhapura and Kurunegala were not. Unfortunately, Ampara was not included in the final analysis and results because of lack of data.

Sri Lanka is an island in the Indian Ocean, to the southeast of India, and has a population of 20.2 million [1]. There are three climatic zones: the southwest forms a wet zone; the northwest and western mountain slopes form an intermediate wet zone; and a dry zone encompasses the north, east and southeast [2, 3]. Malaria transmission has been considered endemic in the dry zone and epidemic-prone in the intermediate zone. The wet zone is historically an area of limited vector breeding as a result of continual precipitation which flushes out the rivers and streams. Malaria transmission is seasonal, typically peaking at the end of the northeast monsoon season (December to March), with a smaller peak after the southwest monsoon (June to October).

The Anti-Malaria Campaign (AMC) Directorate in Colombo guides and coordinates all malaria control activities. Under the purview of the AMC is formulation of national malaria control policy, monitoring national malaria trends, technical guidance to subnational malaria control programmes, inter-district coordination, and coordination of training and research activities. Entomological and parasitological surveillance is also undertaken by the AMC. Decentralization in 1989 shifted the administration of malaria control activities to the districts. Health services are managed by the Regional Director of Health Services (RDHS) and responsibility for malaria control activities rests with the Regional Malaria Officer (RMO) in each district. RMOs work jointly with the Medical Officers of Health (MOHs), whose offices provide varying levels of support for vector control activities.

A civil conflict occurred in Sri Lanka from 1983 to 2009. During this time, a ceasefire was held roughly from 2002 to 2006, The ceasefire officially ended in 2006 when violence resumed in the northeast [4]. Eight districts are considered to have had active conflict from 2005 to 2007, decreasing to six in 2008 and to four in 2009. By May 2009 the war was declared over.

From 1995 to 1999, the number of malaria infections rose from 142,294 to 264,549. Then, from 1999 to 2011, cases were reduced from 264,549 to 175 (124 were indigenous in 2011). The profile of all people infected with malaria, indigenous and imported cases combined, gradually shifted to mostly adult males (ages 15 – 49) with *P. vivax* infections, as opposed to *P. falciparum* infections. Major risk groups for malaria are considered to be male gem miners and male military personnel, and other at-risk groups are considered to be people living along rivers and streams with high vector density and mobile populations, such as chena (slash and burn) cultivators.

In October 2012, Sri Lanka reported its last indigenous malaria case, and by September 2016 the country had achieved malaria free certification from the WHO.

Bhutan

Literature searches were conducted in May and June 2010 from San Francisco. Data collection in Bhutan occurred from July to August 2010 with follow up from San Francisco through the end of 2011. The researcher was based in Thimphu, Bhutan with travel to Gelephu, Bhutan, where the National Vector-borne Disease Control Programme (VDCP) national office is headquartered.

Data collection focused on the period 2000-2010. Data collection and analysis focused on the national malaria programme, based in Gelephu, with some record review occurring in Thimphu, where the Ministry of Health is headquartered. Data collection also occurred in Basic Health

Units and health facilities in Sarpang District, in the south, which had the highest number of malaria cases.

Bhutan spans 38,394 km^2 and has a population of 677,343. It is bordered in the north by the Tibetan Region of China, and by India to the west, south and east with the states of Sikkim, West Bengal, Assam, and Arunachal Pradesh, respectively. The elevation rises to a maximum of 7,314 m and extends down to as low as 160 m above mean sea level in the southern foothills [5, 6]. Bhutan has 20 districts and malaria transmission concentrated in the seven southern districts. Nine districts are considered to have “seasonal” transmission. Bhutan has seasonal rainfall with most malaria cases occurring during the monsoon rain season from June to September [7].

The national malaria programme, or the Vector-Borne Disease Control Programme, coordinates and monitors the district health teams that carry out prevention of malaria and other vector-borne diseases. The national health care system of Bhutan provides the malaria surveillance, case management, and prevention through a community health approach [8].

From 2000 to 2010, malaria cases were reported to decline from 5,935 to 436. Malaria risk areas are mainly forest and forest-fringe human settlements, in particular those with irrigation or development projects, such as hydropower project sites [9]. Four districts in the north-east and central part of the country are not receptive to malaria transmission due to their high elevation and cooler temperatures [10]. Nine districts in a band running east to west across the center of the country are considered at risk for seasonal transmission, having a history of local transmission although some of them have not had an indigenous case in several years. Seven districts are considered malaria-endemic, where transmission occurs throughout the year. These districts border the Indian states of Assam and West Bengal.

Countries in the UCSF-WHO GMP Eliminating Malaria Case-Study Series
Of the nine countries in the cross-case study analysis (Chapters 3 and 4), the researcher conducted primary data collection in Bhutan and Sri Lanka (as described above), and managed the researchers who conducted data collection for the Malaysia, Namibia and the Philippines case-studies. The researcher did not oversee the research for the Cape Verde, Mauritius, Turkey or Turkmenistan case-studies. Therefore only a brief overview of the seven countries and the malaria programmes is given below.

Cape Verde
Cape Verde consists of an archipelago that is 500 km off the coast of Senegal (West Africa). Two island groups, the Barlavento islands and the Sotavento islands, include the ten islands. In 2009, the country’s population was 508,633.

Cape Verde’s goal is to eliminate malaria by 2020. Cape Verde achieved zero cases from 1968 to 1972, then an epidemic occurred during 1977-79. A second elimination attempt occurred 1983 to 85 with a second epidemic during 1987-1988. In 2009, 45 malaria cases were reported in the country.

Malaysia
Located in the Western Pacific region, Malaysia borders Thailand, Brunei and Indonesia. Malaysia is comprised of three states: West Malaysia (located on a peninsula below Thailand), Sabah, and Sarawak. The population in 2011 was 28,859,154.

Malaysia also has a goal of national elimination by 2020, with elimination in West Malaysia by 2015 and elimination in Sabah and Sarawak by 2020. In 2010, there were 6,650 total cases reported.

Mauritius
Mauritius is located in the Indian Ocean to the east of Madagascar. The country is made up of three administrative districts on Mauritius island and three dependencies (Agalega Island, Cargados Carajos Shoals and Rodrigues).

The country eliminated malaria in 1969 and received WHO certification in 1973, but experienced a resurgence in 1975. Elimination was achieved again by 1998. An average of 48 imported and introduced malaria cases were reported every year between 1998 and 2008.

Namibia
Namibia is located in the southwest of sub-Saharan Africa and has a population of 2,212,307. The country is divided into 14 regions.

Namibia has a goal of national elimination by 2020. From 2001 to 2011, reported cases declined from 562,703 to 14,406. Low to moderate transmission transmission occurs in the northern regions that border Angola.

Philippines
The Philippines consists of an archipelago of islands in Southeast Asia in western Pacific Ocean. It is south of Taiwan. The country is made up of 7,107 islands divided into three main island groups: Luzon, Visayas, and Mindanao. There are 80 provinces in the country. The country's population is estimated to be 105.7 million.

The country has adopted a strategy of progressive sub-national elimination with national elimination (all provinces) by 2025 (recently updated to 2030). In 2013, 27 of the 80 provinces were considered to be malaria-free.

Turkey
Turkey is in Eurasia and stretches across the Anatolian peninsula. The Mediterranean Sea and Cyprus are to the south of the country. Turkey's population is estimated to be 73,640 in 2011.

Turkey has eliminated malaria and is considered to be in the prevention of reintroduction of malaria. The final indigenous malaria cases were reported in 2012 during an outbreak. It experienced a resurgence after a first elimination attempt (having nearly achieved elimination in 1974) with epidemics in 1977 and 1993-1996.

Turkmenistan
Turkemenistan is located in Central Asia, to the east of the Caspian Sea. The population in 2009 was 5.1 million. The country is divided into five provinces and 50 districts.

Turkeminstan first eliminated malaria in 1961, then experienced a resurgence. In its most recent attempt, the last indigenous case occurred in 2004 and it received WHO elimination certification in 2010.

2.4 Methods

2.4.1 Mixed methods used for the Bhutan and Sri Lanka Case-Studies
For the Sri Lanka and Bhutan case-studies, a desk review was conducted before in-country data collection, followed by in-country document collection and review, quantitative data collection, and key informant interviews. Quantitative and qualitative data analysis was conducted.

2.4.1.1 Desk review
For the Sri Lanka case-study, a review of published and unpublished literature was conducted before the start of field work. A search was conducted using Google, Google Scholar, Pubmed, World Health Organization Library (WHOSIS) [11], World Health Organization (WHO) Office of the South-East Asia Region [12], and the Global Fund to Fight AIDS, Tuberculosis and Malaria (Global Fund) website using the search terms "Sri Lanka" AND "malaria" AND "case management," OR "diagnosis," OR "treatment," OR "prevention," OR "surveillance," OR "elimination," OR "conflict," OR "*Plasmodium vivax* OR *Plasmodium falciparum*," OR "G6PD." References were also identified by cross-referencing bibliographies of relevant publications. Inclusion criteria included any articles that included the above key words and were in English. The exclusion criteria were not including the key words and articles written in languages other than English.

In the Bhutan case-study, a literature review was conducted using PubMed, Google Scholar, Google, SpringerLink (http://www.springerlink.com), WHO South-East Asia Region Institutional Repository (http://repository.searo.who.int) and the WHO Library database and through requests to the WHO Archives at WHO headquarters in Geneva, Switzerland. Search terms were "Bhutan" AND "malaria" OR "prevention" OR "refugee" OR "Nepal" OR "India" OR "supply, supply system" OR "health system" OR "health supply." Inclusion criteria included any articles that included the above key words and were in English. The exclusion criteria were not including the key words and articles written in languages other than English.

2.4.1.2 In-country document review
A review of published and unpublished literature was also conducted during in-country data collection in Sri Lanka, which included grey literature obtained from the AMC Directorate and

offices of the RMOs during the field data collection period, such as annual reports, administrative reports and plans, and grant reports.

For the Bhutan case-study, published and unpublished literature was gathered and reviewed during in-country data collection in Bhutan. Reports, strategy documents, grant reports and other materials were gathered from the Vector-borne Disease Control Programme headquarters in Gelephu and the Ministry of Health (Thimphu).

2.4.1.3 Quantitative data extraction

In the Sri Lanka case-study, data on malaria testing and incidence were pulled from routine health facility surveillance records of the AMC Directorate and RMOs for 1995 to 2011. The AMC Directorate provided district-level annual estimates of population at risk, IRS activities, and distribution of ITNs and LLINs. Records on expenditures for the costing exercise were gathered from hard copy and electronic files from the offices of the RDHSs and RMOs. Commodities (e.g., LLIN procurement) were identified through record review and interviews at the AMC Directorate in Colombo. Expenditure data were gathered from Ampara, Anuradhapura and Kurunegala. Because of the difficulty in assembling costing data, only two districts – Anuradhapura and Kurunegala – were included in the costing and only two years were chosen - 2004 and 2009 - to represent different phases of the district malaria programme as identified by epidemiological data and programmatic shifts; from endemic or epidemic malaria (2004) to controlled low-endemic malaria (2009). Since malaria programme staff also work on other vector-borne diseases, the key informant interviews and a review of job descriptions were used to determine the proportion of time spent on malaria.

In the Bhutan case-study, routine national health facility surveillance data were collected and reviewed from the Vector-borne Disease Control Programme (Gelephu). Other data collected were estimates of population at risk and distribution and coverage of long-lasting insecticidal nets, insecticide-treated mosquito nets, and indoor residual spraying. Costing data were not extracted for this case-study.

2.4.1.4 Key informant interviews

For the Sri Lanka Case-Study, thirty-three in-person semi-structured key informant interviews were conducted, using an interview guide. Interviews were conducted at the AMC Directorate office and in the RMOs and MOH Area Offices of the districts of Ampara, Anuradhapura and Kurunegala. Interviews were conducted with managers, entomological and parasitological laboratory staff, accountants, technical support staff, IRS spraymen, drivers. No interviews were conducted outside of the public sector. A purposeful sampling method was used to identify knowledgeable subjects for the interviews. The AMC Directorate programme manager identified five RMOs with extensive experience, who in turn suggested other staff members for interviews based on the subjects in the interview guide and the gaps in data. Verbal consent was obtained before the interviews.

Key informant interviews were not conducted for the Bhutan case-study.

2.4.1.5 Analysis

For the Sri Lanka case-study, information from the desk review was used to formulate the Microsoft Excel spreadsheets designed for surveillance data collection and the interview guides. These documents also served to fill gaps in data or were used to confirm or raise questions about conclusions that were developed from the interviews and quantitative data.

Malaria incidence, surveillance and vector control data were plotted in Microsoft Excel. Major malaria indicators and coverage estimates were calculated and trends observed over time. Major political, socio-economic and environmental trends, with a focus on conflict districts, were reviewed. All of these trends were then compared with each other through data triangulation, which is defined as the review, synthesis and interpretation of data from multiple sources. A wide variety of data sources may be examined through data triangulation, from programme data to biological or behavioral data, with a goal of informing public health decision-making [13].

Costs were categorized into personnel, travel, equipment, consumables, and services. They were also grouped by intervention category: prevention, diagnosis, treatment and prophylaxis, surveillance and response, information education and communication (IEC), and programme management. Costs of equipment were amortized using straight-line depreciation. All costs were converted into 2009 U.S. dollars using in-country deflators and 2009 representative country exchange rates [14, 15].

For the Bhutan case-study analysis, malaria incidence, surveillance and vector control data were plotted in Microsoft Excel. Indicators and coverage estimates were calculated and changes over time were reviewed. Programme expenditures were not part of the Bhutan case-study.

2.4.1.6 Ethical considerations

Ethical clearance, with the conduct of verbal consent procedures, was obtained from the Committee on Human Research at the University of California, San Francisco for the Sri Lanka case-study. An approved verbal consent guide was read to participants and their consent was noted. The Ministry of Health in Sri Lanka approved the conduct of the case study. Informed verbal consent was obtained for all key informant interviews and data from the Ministry of Health and Anti-Malaria Campaign were analyzed in aggregate, without information that might identify individuals. The case study was considered to be a low-risk behavioral study thus verbal consent was deemed appropriate.

For the Bhutan case-study, the Ministry of Health in Bhutan approved the conduct of the case study. Data used in the Bhutan Case-study were analyzed in aggregate form and no identifying information was used.

2.4.2 Cross case-study methodology

2.4.2.1 Conceptual framework

For the vector control analysis, a conceptual framework was developed to provide structure for the cross-case analysis. A document review was conducted of malaria elimination vector control guidelines, reports, consultations, and manuals to identify historical and current policy and research on vector control strategies, entomological surveillance, operational research, and costs. Search terms included ‘vector control’ and ‘malaria elimination’ or ‘malaria’; or ‘indoor residual spraying’, ‘insecticide-treated nets’, ‘long-lasting insecticide treated nets’, ‘entomology’, ‘entomological surveillance’, ‘larval control’, and ‘larval source management’ in the following search engines and databases: The Cochrane Library, PubMed, Google Scholar, and WHOSIS. Using this literature, a conceptual framework of vector control strategies and interventions was developed based on the topic areas of vector species and behaviour, approach to vector control, tools and coverage, combination interventions, stratification, outbreak response, implementing organizations, and cost of activities. The framework was reviewed by malaria elimination and vector control experts and formatted in Excel as a matrix.

For the programme management analysis, an initial conceptual framework for programme management in malaria elimination was developed to provide structure for the cross case analysis. This framework was based on a document review, which took place in 2013 and 2014, of malaria elimination guidelines, reports, consultations and manuals to identify historical and current policy and research on management strategies, tools, and operational research. The following search terms were used to gather materials: “programme management,” “supervision,” “decentralization,” “vertical,” “integration,” “health systems,” “incentives,” “training,” “financing,” “costs,” “human resources” and “malaria,” “malaria control,” “malaria elimination” in Pubmed and Google Scholar (English only). The framework was formatted in Excel as a matrix.

One of the results of the workshop (described below) was consensus that the programme management framework needed to be revised to better capture the available data and draw firmer conclusions of major programme strengths and weaknesses. Inputs from the workshop were considered and additional documents were collected and original documents re-reviewed to develop the new framework. Using the revised framework, a second round of in-depth review of the nine case-study reports, data extraction, summary and analysis was completed.

2.4.2.2 Data extraction

Using the matrices, each case study report was reviewed for information (e.g., examples, synthesis or analysis). If there was programme experience for a particular concept, it was summarized in detail in the corresponding matrix cell. Otherwise the cell was left blank. After reviewing a given report across all concepts, a summary of the experience with a note as to how strong of an example it was (by subjective assessment) was written into the cell. After all of the reports were reviewed and cells filled in, main challenges and weaknesses of each programme experience were summarized by the researchers.

After the workshop (described below), a second round of data extraction from the case-study reports was conducted to ensure that data in the matrices was complete and to identify information that covered concepts that were added by workshop participants.

2.4.2.3 Workshop

A two-day workshop was held in February 2014 to review the matrices on vector control and programme management, along with other themes that were not pursued for analysis of this type. Workshop participants were selected from the WHO Global Malaria Programme / UCSF Global Health Group Case Study Advisory Committee, which consisted of malaria elimination researchers and experts. Before the workshop, these workshop participants conducted in-depth reviews of two case-study reports and the matrices, and were asked to compare the information presented in the reports against the qualitative descriptions of experience, synthesis and analysis entered into the cross case-study matrix and summaries. This work was undertaken to ensure that the data captured in the matrix were comprehensive, and to debate the lessons learned across the case-study experience.

2.4.2.4 Analysis

During the analysis phase, each concept from the frameworks was written out in Microsoft Word and data and information from each matrix cell (a country's experience in detail) was written out. Using this document, the researcher compared countries, identifying any common experiences, successes, challenges, or gaps in information. First the researcher reviewed country experiences by dividing the countries into two groups: those that had successfully eliminated and those who had not. A second grouping was used for the programme management analysis: those countries that had experienced resurgence after eliminating or nearly eliminating and those that had not experienced resurgence.

For the vector control theme, results of the cross case-study analysis were compared with the strategies laid out in the new Global Technical Strategy.

For the programme management theme, results of the analysis were compared with documentation of successful strategies from non-malaria eradication programmes, such as smallpox and polio. This was because there was not a great deal of malaria elimination and eradication programme management-related documents available. Because the programme management conceptual framework included elements that were not necessarily controlled by malaria programmes, an effort was made to divide the Discussion into programme areas for which programmes had no control, some control and all control to change or improve.

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CHAPTER 3

Malaria Control and Elimination in Sri Lanka: Documenting Progress and Success Factors In A Conflict Setting

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Abeyasinghe RR, Galappaththy GNL, Smith Gueye C, Kahn JG, Feachem RGA (2012). Malaria control and elimination in Sri Lanka : Documenting progress and success factors in a conflict setting. *PLoS ONE* **7:**e43162.

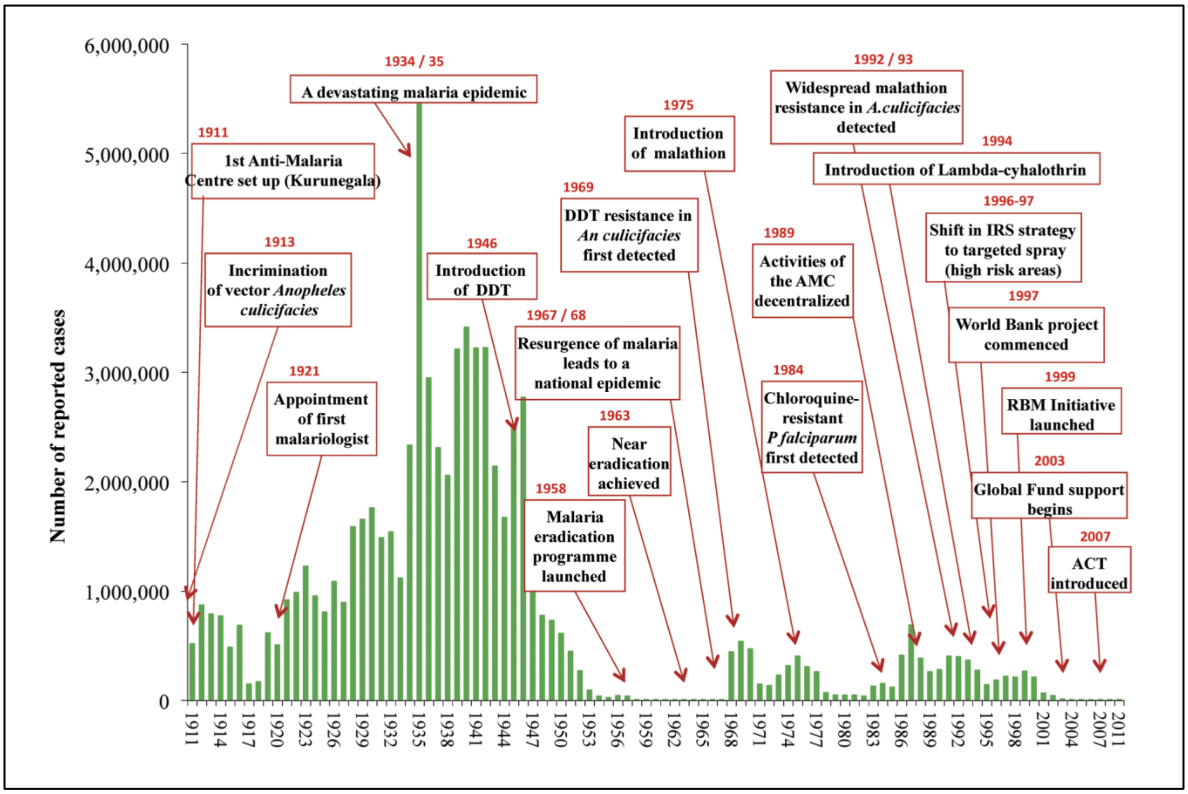
3.1. Abstract

Background: Sri Lanka has a long history of malaria control, and over the past decade has had dramatic declines in cases amid a national conflict. A case study of Sri Lanka's malaria programme was conducted to characterize the programme and explain recent progress. Methods: The case study employed qualitative and quantitative methods. Data were collected from published and grey literature, district-level and national records, and thirty-three key informant interviews. Expenditures in two districts for two years – 2004 and 2009 – were compiled. Results: Malaria incidence in Sri Lanka has declined by 99.9% since 1999. During this time, there were increases in the proportion of malaria infections due to *Plasmodium vivax*, and the proportion of infections occurring in adult males. Indoor residual spraying and distribution of long-lasting insecticide-treated nets have likely contributed to the low transmission. Entomological surveillance was maintained. A strong passive case detection system captures infections and active case detection was introduced. When comparing conflict and non-conflict districts, vector control and surveillance measures were maintained in conflict areas, often with higher coverage reported in conflict districts. One of two districts in the study reported a 48% decline in malaria programme expenditure per person at risk from 2004 to 2009. The other district had stable malaria spending. Conclusions: Malaria is now at low levels in Sri Lanka – 124 indigenous cases were found in 2011. The majority of infections occur in adult males and are due to *P. vivax*. Evidence-driven policy and an ability to adapt to new circumstances contributed to this decline. Malaria interventions were maintained in the conflict districts despite an ongoing war. Sri Lanka has set a goal of eliminating malaria by the end of 2014. Early identification and treatment of infections, especially imported ones, together with effective surveillance and response, will be critical to achieving this goal.

3.2 Introduction

In AD 300, the former capital city of Sri Lanka, Anuradhapura, was devastated by a “pestilence” that was likely malaria. From AD 1300 onwards, indigenous medical literature describes a fever that echoes the “chill, rigor, gooseskin, and headache” of malaria [1]. In 1908 the first spleen survey was carried out and by 1921, the island, then known as Ceylon, appointed its first malariologist [1,2]. Epidemics occurred every three to five years, a major one occurring from 1934-1935 that led to an estimated 5.5 million cases (Figure 3.1) [1]. In 1945, Sri Lanka became the first country in the region to develop a scheme for indoor residual spraying (IRS) using DDT and established its first mobile spray unit. IRS was quickly expanded to all malarious areas [1]. At the same time, “vigilance units” conducted parasitological and entomological surveillance, including active surveillance [3,4]. In 1954 as a result of declining cases, IRS was reduced but then was quickly redeployed in response to rising malaria [1]. In 1958, Sri Lanka joined the Global Malaria Eradication Programme [5].

Figure 3.1: Timeline of reported cases and major events in Sri Lanka 1911-2011



A massive decline in incidence occurred in Sri Lanka, from 91,990 cases in 1953 to 17 cases in 1963 [3,6,7]. Then, as was the case for many other countries [8,9], IRS was scaled down, surveillance and control activities were relaxed, and financial support reduced [1,10-12]. In combination with reduced rainfall in the wet zone [13], these actions led to a massive resurgence, with an estimated 1.5 million cases during the two-year period 1967-1968 [14]. IRS was scaled back up the next year, but the damage had already been done. Major epidemics have since occurred in Sri Lanka in the 1980s and early 1990s [15].

Since 1999, Sri Lanka has seen a dramatic decline in malaria once again. This success is notable given the major operational challenges posed by nearly 30 years of civil war between the Liberation Tigers of the Tamil Eelam (LTTE) and the Sri Lankan Government (1983 to 2009). There are many examples throughout the world of the negative consequences of conflict on the function of malaria control programmes [16-19]. However, from 1999 onwards, Sri Lanka achieved major reductions in incidence and may now be considered a controlled low-endemic country [20,21]. A century (1911-2011) of malaria incidence and relevant events is summarized in Figure 3.1. Sri Lanka aims to interrupt indigenous malaria transmission, or eliminate [8], *Plasmodium falciparum* by the end of 2012 and *Plasmodium vivax* by the end of 2014 (Table 3.1) [6,22-24].

Table 3.1 Malaria transmission factors in Sri Lanka

Proportion of cases due to *Plasmodium vivax*	90.3% (2011)
Populations considered to be most at risk	Security forces personnel, gem miners, mobile populations
Vectors	Principal vector is *Anopheles culicifacies*, species E; *An. subpictus* is considered a minor vector
Malaria geography and seasonality	Malaria transmission has historically occurred north, east and southeast; Malaria transmission typically peaks from December to March, with a smaller peak from June to October.

While the history of Sri Lanka's battle with malaria is interesting, this case study focuses on the last 15 years of the successful malaria programme of Sri Lanka, describing the malaria epidemiology and the important factors that have led to the sustained decline in malaria. The aim is to provide a description of the country's experience and the lessons learned as it has moved toward elimination, from which other countries may benefit. Socio-economic and political enabling and challenging factors are described, with a particular focus on the civil conflict and whether surveillance and vector control efforts were maintained in conflict areas. Expenditures on malaria control were measured in two districts, to see how the cost of malaria control per capita at risk changed as the country moved from a highly endemic period to one of controlled, low-endemic malaria.

3.3 Methods

3.3.1 Geography, population and climate

Sri Lanka is an island in the Indian Ocean, to the southeast of India. This lower-middle income country has a population of 20.2 million [25]. Sri Lanka has 25 districts, of which six are considered to be at very low to no risk for malaria. Cases reported in these districts are likely to have originated in other districts. Malaria transmission is seasonal, typically peaking at the end of the northeast monsoon season (December to March), with a smaller peak after the southwest monsoon (June to October). There are three climatic zones: the southwest forms a wet zone;

the northwest and western mountain slopes form an intermediate wet zone; and a dry zone encompasses the north, east and southeast [13,26]. Malaria transmission has been considered endemic in the dry zone and epidemic-prone in the intermediate zone. The wet zone is historically an area of limited vector breeding as a result of continual precipitation which flushes out the rivers and streams.

3.3.2 Data sources

Desk research

A review of published and unpublished literature was conducted before the start of field work, then again during and after in-country data collection. Documents collected before field work informed the key informant interviews and quantitative data collection. Documents collected during and after field work were used in the analysis, as described below. A search was conducted using Google, Google Scholar, Pubmed, World Health Organization Library (WHOLIS) [27], World Health Organization (WHO) Office of the South-East Asia Region [28], and the Global Fund to Fight AIDS, Tuberculosis and Malaria (Global Fund) website using the search terms “Sri Lanka” AND “malaria” AND “case management,” OR “diagnosis,” OR “treatment,” OR “prevention,” OR “surveillance,” OR “elimination,” OR “conflict,” OR “*Plasmodium vivax* OR *Plasmodium falciparum*,” OR “G6PD.” References were also identified by cross-referencing bibliographies of relevant publications. The review included grey literature obtained from the Anti-Malaria Campaign Directorate and offices of the Regional Malaria Officers (see Programme structure section, below) during the field data collection period, such as annual reports, administrative reports and plans, and grant reports. Inclusion criteria included any articles that included the above key words and were in English. The exclusion criteria were not including the key words and articles written in languages other than English.

Quantitative data

Data on malaria testing and incidence were pulled from routine health facility surveillance records of the Anti-Malaria Campaign (AMC) Directorate and Regional Malaria Officers (RMOs) for 1995 to 2011. The AMC Directorate provided district-level annual estimates of population at risk, indoor residual spraying (IRS) activities, and distribution of insecticide-treated nets (ITNs) and long-lasting insecticide-treated net (LLINs).

Most expenditure records were gathered from hard copy and electronic files from the offices of the Regional Directors of Health Services (RDHSs) and Regional Malaria Officers. Commodities (e.g., LLIN procurement) were identified through record review and interviews at the AMC Directorate in Colombo. Costs were reported in Sri Lankan Rupees (LKR) and U.S. Dollars (USD). The costing analysis does not include expenditures or contributions to the malaria programme from non-public sector entities, such as by households, non-governmental organizations (NGOs), or Global Fund support through organizations outside of the public sector.

Expenditure data were gathered from two of the largest malarious districts, Anuradhapura and Kurunegala. The districts were chosen based on their differing characteristics, level of experience of malaria programme managers, and safety of travel to the districts at the time of this study [29]. Because of the difficulty in assembling costing data, two years were chosen - 2004 and 2009 - to represent different phases of the district malaria programme as identified by epidemiological data and programmatic shifts; from endemic or epidemic malaria (2004) to controlled low-endemic malaria (2009). Since malaria programme staff also work on other vector-borne diseases, the key informant interviews and a review of job descriptions were used to determine the proportion of time spent on malaria.

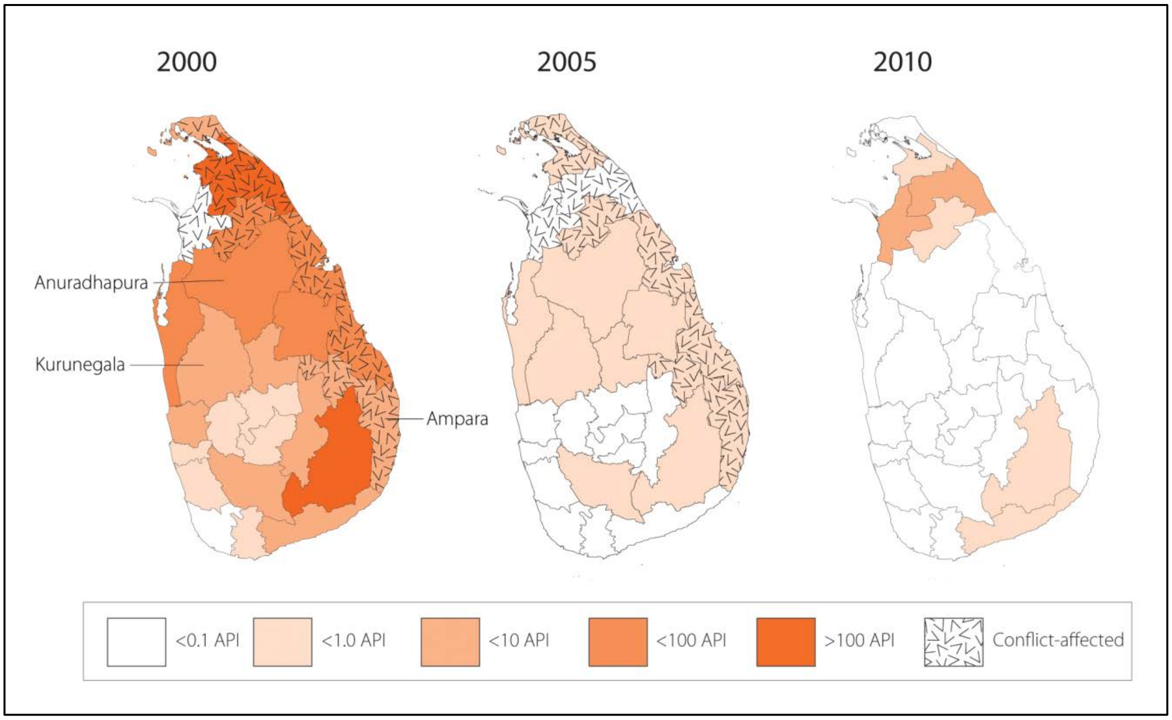
Key informant interviews

Thirty-three in-person semi-structured key informant interviews, using an interview guide, were conducted at the AMC Directorate office and in the RMOs and Medical Officer of Health Area (MOH Areas) Offices of the districts of Ampara, Anuradhapura and Kurunegala. Seven interviews were conducted at the AMC Directorate, including managers, entomological and parasitological laboratory staff, and accountants. Nineteen total interviews were conducted at RMOs in the three sample districts, ranging from programme managers to entomologists, technical support staff to IRS spraymen to drivers. Six interviews were conducted at Medical Officer of Health Areas, ranging from managers to spraymen. One interview was conducted at a Regional Director of Health Services office with an accountant. No interviews were conducted outside of the public sector. A purposeful sampling method was used to identify knowledgeable subjects for the interviews. The AMC Directorate programme manager identified five RMOs with extensive experience, who in turn suggested other staff members for interviews based on the subjects in the interview guide and the gaps in data. Verbal consent was obtained before the interviews.

Political, environmental and socio-economic data

There was a civil conflict between government forces and the LTTE from 1983 to 2009. While government forces reclaimed two eastern districts in 2008, the remaining conflict districts shown in Figure 3.2 remained under LTTE control until the war was declared over in May 2009. A conflict variable was created, whereby districts were considered to be "non-conflict" if they were under government control without indication of active conflict. The sources of data for this variable were the Sri Lanka Ministry of Defense conflict maps and the LexisNexis Academic database, with a search of terms "Sri Lanka," AND "conflict" OR "war" OR "LTTE" [30]. If there was a conflict between these two sources, the Ministry of Defense reports were used as the deciding factor.

Figure 3.2: Map of Annual Parasite Incidence (API) (confirmed infections/1,000 population at risk) by district, 2000, 2005, and 2010. API per 1,000/population at risk. The costing analysis was conducted in Anuradhapura and Kurunegala districts. Key informant interviews were conducted with representatives from Ampara, Anuradhapura, and Kurunegala districts. The Malaria Atlas Project (MAP) and the Sri Lanka Ministry of Health provided the base district-level map of Sri Lanka. MAP is committed to disseminating information on malaria risk, in partnership with malaria endemic countries, to guide malaria control and elimination globally.



Population health, health expenditure, and economic indicators were accessed from the World Bank [25].

3.3.3. Analysis

The quantitative and qualitative data were reviewed to identify factors that contributed to the decline in malaria in Sri Lanka, including an estimate of the coverage of vector control and surveillance across conflict and non-conflict districts. Information from the literature found in the desk review collected before the commencement of field work was used to formulate the quantitative and qualitative data collection tools, such as the interview guides and Microsoft Excel spreadsheets for surveillance data. These documents, in addition to new sources of grey literature accessed during and after in-country data collection, served to identify the major changes in malaria control strategies and interventions. These preliminary findings were compared to the qualitative and quantitative data collected in the field. In later stages of analysis, these documents served to fill gaps in data or were used to confirm or raise questions about conclusions that were developed from the interviews and quantitative data.

Annual, district-level data on malaria incidence, surveillance and vector control activities were plotted in Microsoft Excel. Major malaria indicators and coverage estimates were calculated and trends observed over time. Major political, socio-economic and environmental trends, with a focus on conflict districts, were reviewed. All of these trends were then compared with each other through data triangulation, which is defined as the review, synthesis and interpretation of data from multiple sources. A wide variety of data sources may be examined through data triangulation, from programme data to biological or behavioral data, with a goal of informing public health decision-making [31]. If differences emerged across data sources in the case study, the key informant interviews were considered the primary source of information.

Costs were categorized into personnel, travel, equipment, consumables, and services. They were also grouped by intervention category: prevention, diagnosis, treatment and prophylaxis, surveillance and response, information education and communication (IEC), and programme management. Costs of equipment were amortized using straight-line depreciation. All costs were converted into 2009 U.S. dollars using in-country deflators and 2009 representative country exchange rates [32,33]. As district-level costs included contributions by only the RDHS or district-level budget and Global Fund support, funding provided by the national Ministry of Health for malaria (e.g., some personnel) was estimated and allocated proportionally across each intervention for the two districts. The national budget report was used to calculate funding provided by the Ministry of Health. The 2008 national budget report was used to calculate funds for malaria for 2009. National costs for 2004 and 2008 were assigned to districts in proportion to total district spending on malaria control.

3.3.4 Ethical considerations

Ethical clearance, with the conduct of verbal consent procedures, was obtained from the Committee on Human Research at the University of California, San Francisco. An approved verbal consent guide was read to participants and their consent was noted. The Ministry of Health in Sri Lanka approved the conduct of the case study. Informed verbal consent was obtained for all key informant interviews and data from the Ministry of Health and Anti-Malaria Campaign were analyzed in aggregate, without information that might identify individuals. The case study was considered to be a low-risk behavioral study thus verbal consent was deemed appropriate.

3.4 Results

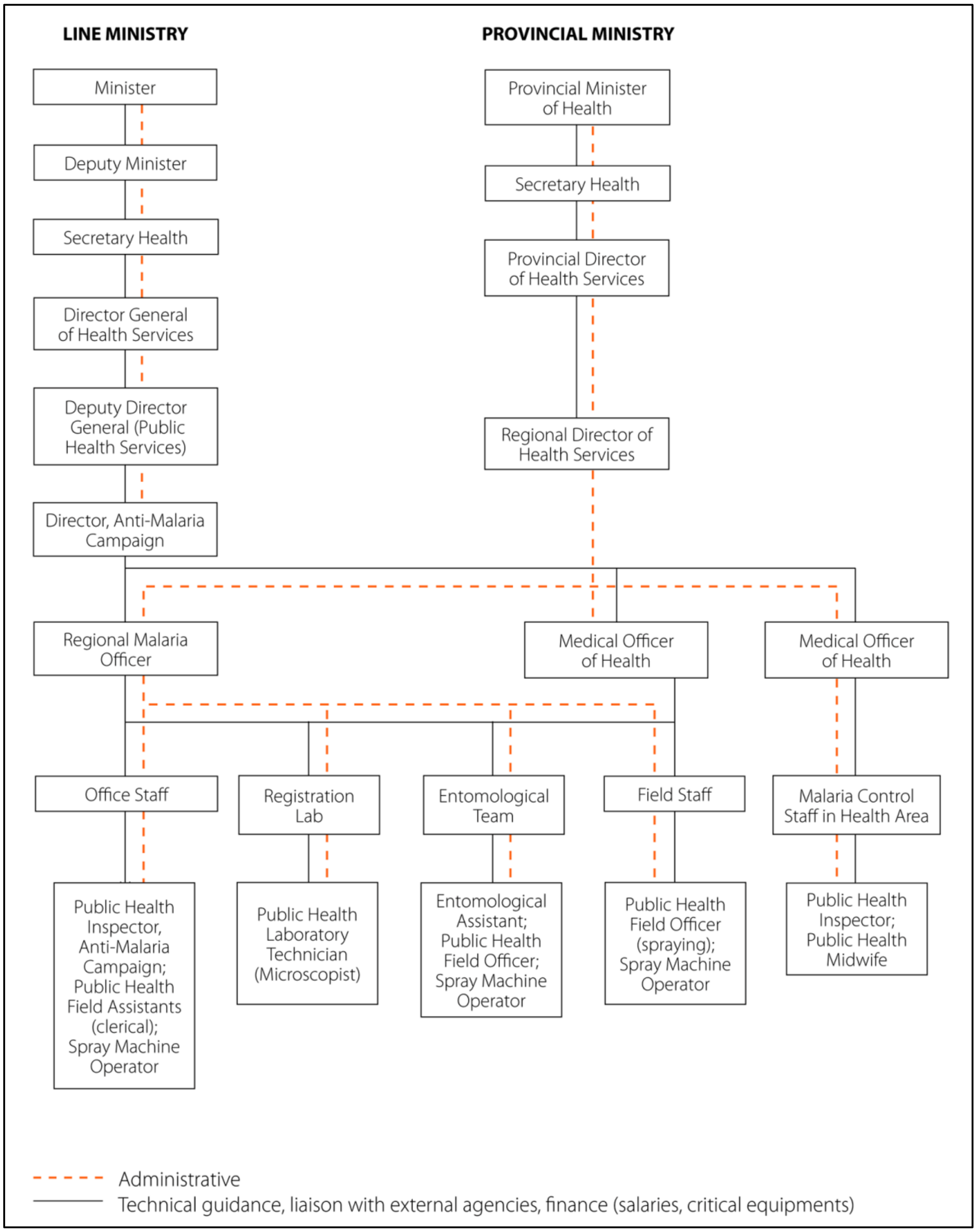
3.4.1 Desk research

The desk research identified 112 publications related to malaria control and elimination in Sri Lanka. Roughly a quarter (26) of these publications are studies on vector control in Sri Lanka. There were 72 grey documents identified and reviewed, 56 of which were reports from the Anti-Malaria Campaign, the Sri Lanka Ministry of Health, or reports written by consultants about a project implemented by either organization. There were 16 documents reviewed from the World Health Organization.

3.4.2 Programme structure

The Anti-Malaria Campaign (AMC) Directorate in Colombo guides and coordinates all malaria control activities (Figure 3.3). Under the purview of the AMC is formulation of national malaria control policy, monitoring national malaria trends, technical guidance to subnational malaria control programmes, inter-district coordination, and coordination of training and research activities. Entomological and parasitological surveillance is also undertaken by the AMC. Decentralization in 1989 shifted the administration of malaria control activities to the districts. Health services are managed by the Regional Director of Health Services (RDHS) and responsibility for malaria control activities rests with the Regional Malaria Officer (RMO) in each district. RMOs work jointly with the Medical Officers of Health (MOHs), whose offices provide varying levels of support for vector control activities.

Figure 3.3: Organizational diagram of the Sri Lanka Anti-Malaria Campaign



3.4.3 Challenging and enabling factors

Conflict

Sri Lanka's long-running civil conflict affected the whole country but was concentrated in an estimated eight districts [34]. A ceasefire agreement was declared in 2002, and there was a decline in civilian casualties around this time: a decline in "battle-related deaths" was reported from 4,000 (2000) to 1,000 (2001), then down to zero in 2002 and 2004 [25]. The ceasefire also linked the Jaffna Region in the north to the rest of Sri Lanka through regular commercial passenger flights and the reopening of route A9, a major artery for transportation between Jaffna and Colombo [34,35]. As a result, delivery of supplies to the northern areas may have increased. However, for the purposes of this case study, the number of districts considered to have conflict during these years remained at eight because reports indicate that the ceasefire was not respected by both sides at all times and sporadic fighting continued [34].

The ceasefire officially ended in 2006 when violence resumed in the northeast [34]. The same eight districts are considered to have had active conflict from 2005 to 2007, decreasing to six in 2008 and to four in 2009. Over this period deaths related to the conflict rose, peaking in 2008 (11,144) [25]. By May 2009 the war was declared over and by December route A9 was again open.

Socio-economics, health and environmental factors

National gross domestic product (GDP) per capita increased from $715 (current USD) in 1995 to $2,375 in 2010 [25]. Total health expenditure per capita (current USD) also rose from $26 in 1995 to $84 in 2009. The adult literacy rate in Sri Lanka was estimated to be 91% both in 2001 and in 2006. 76.6% of the population was reported to have access to electricity across the country in 2009 [25].

Historically, transmission of malaria has increased in Sri Lanka when pooling occurs in rivers and streams, which is conducive for the breeding of the primary vector, *Anopheles culicifacies.* Transmission increases with monsoon rain events in the dry zone. Transmission may also increase when the monsoon is weak or does not occur in the intermediate zone [7]. The literature did not report any major droughts, flooding, or shifts in vector breeding during the period 1995-2011. However, the World Bank Health Services Project reported that a drought in 2001 may have contributed to project-area declines in malaria incidence [36]. Studies have had reasonable success in linking rainfall to malaria incidence, when using a two to three month period for forecasting [37].

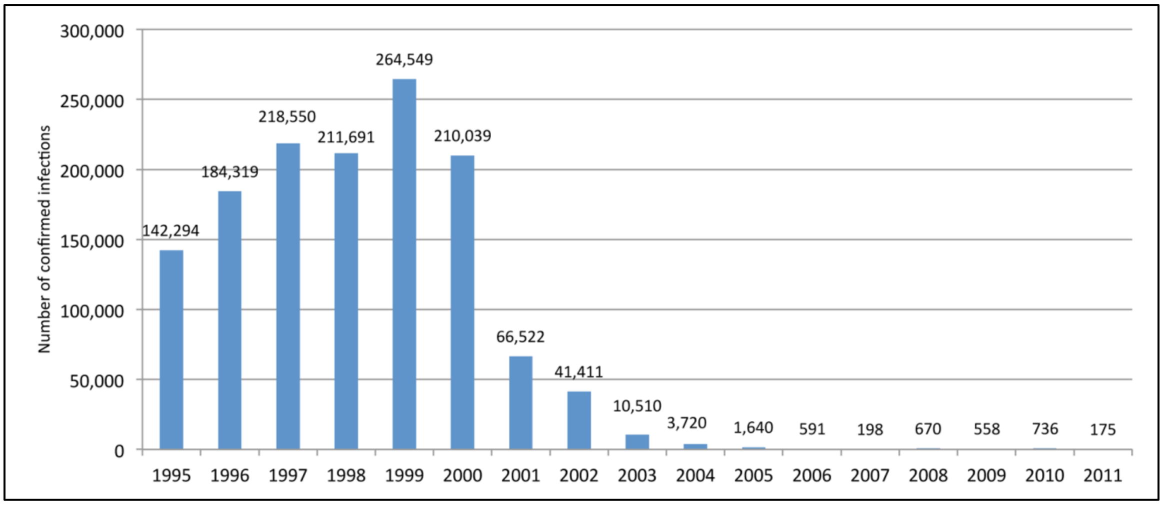
The tsunami of December 2004 led to a massive loss of life and displacement of 860,000 people. Hospitals and administrative buildings were destroyed [38]. However, reports indicate that surveillance and prevention activities for malaria were maintained by local health authorities and NGOs and no malaria epidemic accompanied the tsunami (2004-2005) [39].

3.4.4 Epidemiology of malaria and vectors

From 1995 to 1999, the number of malaria infections confirmed by microscopy or rapid diagnostic tests (RDTs), or confirmed infections, rose from 142,294 to 264,549 (Figure 3.4).

Then, beginning in 2000, cases began to decline. From 1999 to 2007, cases were reduced from 264,549 to 198 (99.9%). There was a small uptick in total cases, combined indigenous and imported, to 670 in 2008 through to 2010 (736). In 2011, 175 cases were confirmed, of which 124 were indigenous, meaning that the infection originated in Sri Lanka.

Figure 3.4: Total confirmed infections from Active and Passive Case Detection, Sri Lanka, 1995 to 2011

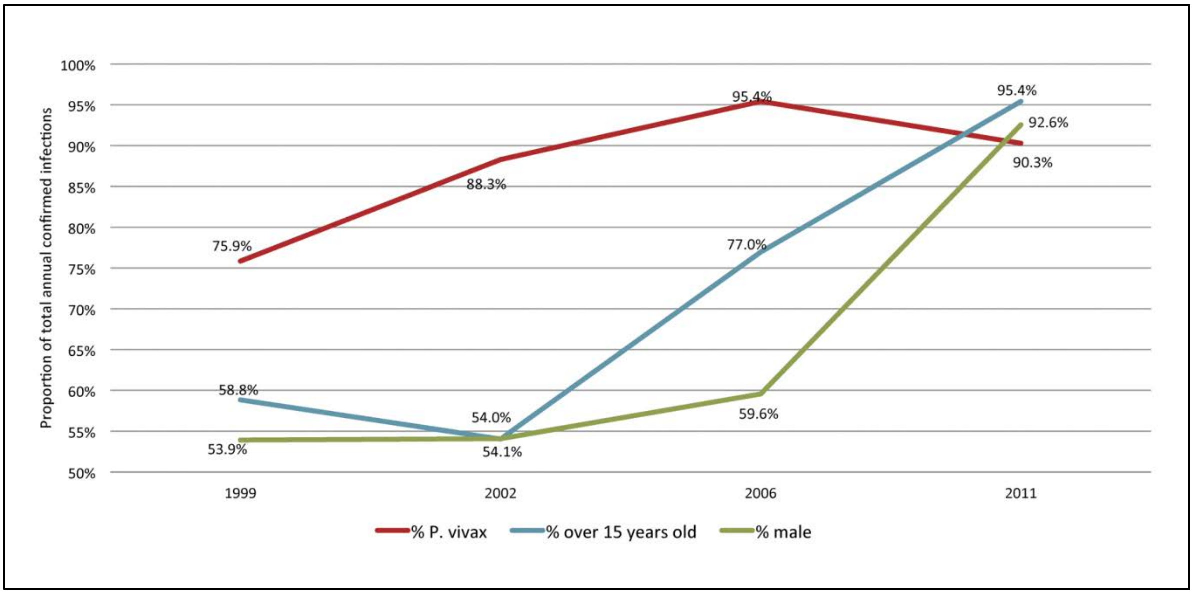


Malaria-related mortality in Sri Lanka has similarly declined, from a peak of 115 deaths in 1998 to zero indigenous deaths each year since 2008. In years 2009 and 2011 there was one death, each an imported case from Nigeria.

Annual parasite incidence (API), or the number of confirmed infections of all Plasmodium species divided by the estimated population at risk, was 11.9 per 1,000 in 1995, reached a peak of 22.1 in 1999, then declined to less than 1 by 2004 (0.9). In 2010 the estimated API of indigenous cases was 0.1. The slide positivity rate (SPR), or the proportion of slides found positive for indigenous cases for any Plasmodium parasites among the slides collected [40], was 13.0% in 1995, peaked in 1999 at 16.7%, then declined starting in 2000 (11.8%) to 0.2% in 2005. In 2010 the SPR was 0.1%. Studies employing polymerase chain reaction (PCR) assay have found no evidence of sub-microscopic parasitaemia in previously endemic portions of the country [41,42].

As national malaria morbidity declined, the profile of all people infected with malaria, indigenous and imported cases combined, became mostly adult males (ages 15 – 49) with *P. vivax* infections, as opposed to *P. falciparum* infections. The proportion of all confirmed cases occurring in persons over the age of 15 was 58.8% in 1999, 77.0% in 2006, and 95.4% in 2011 (Figure 3.5). In 1999, 53.9% of all infections were in males. By 2006 this grew to 59.6% and in 2011 reached 92.6% of cases. The proportion of infections due to *P. vivax* in all cases, including indigenous and imported, grew from 75.9% in 1999 to 95.4% in 2006 before leveling off at 90.3% in 2011. One *P. ovale* infection was diagnosed in 2005, then one *P. malariae* in 2008, which was acquired outside of Sri Lanka.

Figure 3.5: Annual percentage of confirmed infections for 1999, 2002, 2006 and 2011. All percentages represent total cases, indigenous and imported cases combined.



Male gem miners and male military personnel became a major risk group for malaria infection. Other at-risk groups are considered to be people living along rivers and streams with high vector density and mobile populations, such as chena (slash and burn) cultivators.

Conflict zone

Non-conflict districts (17 districts) had a similar API (33.0) to the eight conflict districts (29.9) in 1995, but by 2000 conflict districts accounted for the majority of infections (71.5 average API in conflict and 35.1 in non-conflict districts). In 2005, when national incidence was much lower, API across both areas was the same (0.4). Figure 3.2 shows the spatial distribution of API across districts during 2000, 2005, and 2010.

The SPR was higher in conflict districts throughout most of the study period. In 1995, conflict districts had an SPR of 17.0% compared to 11.7% for non-conflict districts. As seen with API, by 2005 the SPR was the same across both regions (0.2%) and has not changed in recent years.

3.4.5 Vectors

The principal vector in Sri Lanka is of the *Anopheles culicifacies* species E of the complex which has sibling species A, B, C, D, and E [22,23]. Species B is considered a poor vector in Sri Lanka [23]. The species complex is largely found in stream habitat [43]. Species E can be found in a wider range of habitat, mainly in river margins in the rock and sand pools, agricultural sites, and in wells and irrigation channels [23]. Throughout its history, Sri Lanka has had major irrigation projects, funneling its rivers into dams, reservoirs and tunnels [7]. The vector is considered both endo- and exophagic (outdoor and indoor feeding behavior), primarily endophilic (indoor resting), an “intensely domestic species,” and has a dusk to night biting time [2,44]. *An. culicifacies* is considered to be zoophilic in nature, except Species E [23]. In southeastern Sri Lanka in the 1990s, which was a period of higher endemicity, the entomological inoculation rate (EIR) of the ten Anopheles species studied was estimated at 0.0029 infectious bites per person per night for *P. vivax* and 0.0109 for *P. falciparum* [45]. More recent EIR estimates are not available as the number of vectors have been extremely low and finding sporozoite-infected mosquitoes even more challenging.

Another important vector on the island is *An. subpictus*, of which two sibling species are present in Sri Lanka, Species A and B. Species A is associated with inland areas and Species B with coastal areas [24]. *An. subpictus* is found in coastal and brackish water, and pools and rice fields [44]. This vector is also considered to be zoophilic and is both endo- and exophagic [44]. It is endophilic in nature and bites at dusk or night. A study in the eastern part of Sri Lanka in 1989 and 1990 estimated an EIR for *An. subpictus* ranged from 0.00006 to 0.007 infectious bites per night for *P. vivax* and from 0.0002 to 0.005 for *P. falciparum* [46].

3.4.6 Parasitological surveillance

Two main surveillance measures are used in Sri Lanka – passive and active case detection. “Activated passive case detection,” or APCD, is a form of passive case detection used in Sri Lanka comprised of dedicated malaria-only screening facilities in public health facilities. APCD capacity increased in the late 1990s by a near doubling of the number of microscopists in district hospitals. Outside of APCD facilities, health facilities conduct passive case detection without malaria-specific screening centers. All of these facilities rely mostly on microscopy. RDTs were distributed starting in 2001, but are only for emergencies, such as in the months following the tsunami. 45,000 RDTs were procured in 2004 with Global Fund funding. If all RDTs were used, this figure would represent only 4% of the 1.2 million malaria tests conducted that year.

Limited clinical diagnosis still occurs but is discouraged by the Directorate, and clinicians are instructed to take a blood film two weeks later if possible. Quality control of microscopically-confirmed diagnosis occurs at the regional and national laboratories: regional laboratories perform quality control of all positive and negative blood smears while the national reference laboratory carries out quality control on all positive tests, including RDT-positive, and 10% of negative smears.

Active case detection (ACD) was introduced in 1997. Over the years, mobile malaria clinics have targeted mobile populations resulting from the conflict and remote, inaccessible populations in all areas. Today ACD is also part of the reactive case investigation procedures (focal screening). The aim is to detect asymptomatic and symptomatic parasite carriers, including relapsing *P. vivax* cases, who may contribute to post-monsoon epidemics. RDTs are occasionally used for these clinics, but the majority of tests are conducted by microscopy. The World Bank International Development Association (IDA) supported initial ACD activities and the Global Fund increased support for them starting in 2003.

The annual blood examination rate (ABER), or the number of blood slides collected out of the total national population, was 6.1% in 1995, 9.4% in 2000, and declined to 5.0% in 2005 with little change through 2010 (4.8%).

In all years, the majority of confirmed cases nationwide were identified through APCD. In 1995, 89.8% of cases were identified through this method, with no significant change in 2000 (89.4%). APCD identified 94.0% of all cases in 2005. ACD accounted for only a small percentage of positive cases (0.9%) in 1997 and 2000 (1.1%), rising to 13.1% in 2007. Passive case detection and other blood surveys found the remaining confirmed infections.

As the number of cases declined after 1999, district-level staff had more time to dedicate to case investigation. In 2009, the AMC Directorate developed standard operating procedures (SOPs) for every confirmed or suspected infection, which include follow-up of confirmed infections for 28 days post-treatment together with case investigation procedures and additional measures, such as household malaria screening, entomological surveillance within 24 hours, and focal IRS in a one-kilometer radius. Also in 2009, the programme instituted case investigation reviews, where each case and the follow up measures taken are reviewed in detail by AMC Directorate staff and Regional Malaria Officers, at a meeting in the capital. The information gathered in the case investigation and in the case reviews is used to detect any deviations in vector behaviour (see Entomological Surveillance section, below) as well as to monitor clinical manifestations and parasite clearance time. The results of these investigations, in combination with mapping with geographical information systems (GIS) technology, which commenced three years ago, are used for the purpose of epidemic forecasting, the cornerstone of the national malaria elimination strategy. The programme continually seeks to strengthen surveillance in order to quickly detect epidemics.

In 2008, the AMC Directorate introduced individual case reporting to the AMC and a year later a policy of 24-hour case reporting was implemented. Regional Malaria Officers report cases by email, by phone or through the hotline maintained by the AMC Directorate. An elimination surveillance database was developed to house this information and for rapid analysis. There is a national health information system and there is a national requirement to report malaria cases to this system. However, the AMC uses a separate, web-based system that enables the programme to conduct 24-hour reporting. The AMC expects to integrate the malaria reporting system with the national system and with other diseases once malaria is eliminated from the country.

Monitoring and evaluation is an important aspect of the surveillance system and the entire programme, and the systems in place have been greatly strengthened through implementation of the Global Fund grants. A framework and plan for monitoring and elimination was developed in 2010, based on the framework put forward in 2009 by the Roll Back Malaria (RBM) – Malaria Evaluation Reference Group (MERG) [47]. Indicators for disease surveillance and management as well as vector surveillance and control are included in the plan. Monitoring and evaluation of malaria activities is coordinated by the Regional Malaria Officers, at the district level, and at the national level by the AMC Directorate. Data is collected at the periphery at the smallest administrative level (Grama Niladari Division), with processing carried out by the RMOs and Medical Officer of Health Area staff [48]. Data is used either immediately for corrective action or is processed upwards to the district, provincial, and national levels. Feedback to the periphery occurs typically through the case review monthly meetings with districts teams, as mentioned above, and includes other stakeholders. However, when urgent this feedback will occur more rapidly.

Conflict zone

Since 1995, average ABER was higher in conflict districts. Conflict districts had an average ABER of 9.9% in 1995, compared to 5.4% in non-conflict districts. Conflict districts nearly doubled their ABER to 18.5% by 2000 while non-conflict districts only had a minor increase to 7.9%. By 2009, ABER decreased to 10.4% in conflict districts and 4.2% in non-conflict districts in 2009.

Conflict districts in some years had a slightly higher average per capita rate of ACD testing because the mobile clinics targeted hard to reach, at-risk populations, a majority of them located in the conflict areas. The per capita rate of ACD testing in conflict districts peaked in 2008 at 6.3% when 107,629 blood films were taken by these clinics. That year, 0.4% of the population in non-conflict districts was tested through ACD clinics.

In conflict districts, RMOs and their staff remained in their posts and were provided with vehicles and RDTs to conduct mobile clinics whenever it was safe to do so. There were reports of LTTE members assisting with and as beneficiaries of ACD clinics. In addition, the Sri Lankan Red Cross, the International Committee of the Red Cross (ICRC), and Medecins Sans Frontieres (MSF) assisted in providing diagnosis and treatment services. In addition, a Sri Lankan private not-for-profit organization, Tropical and Environmental Diseases and Health Associates (TEDHA), trains and deploys microscopists to APCD facilities in previous conflict districts as part of the Global Fund Round 8 grant, contributing to the scale-up of surveillance since 2009.

3.4.7 Entomological surveillance

An entomological surveillance system was created in Sri Lanka shortly after the 1934-1935 epidemic, aiming to forecast increases in seasonal transmission and potential epidemics through identification of changes in vector breeding [3]. Trained mosquito collectors collected larvae and adult mosquitoes in dwellings on a monthly schedule. In 1940 the programme added mandatory inspections of rivers and streams for larvae by public health inspectors in each jurisdiction [3].

These activities continue today at both the central and district level. Routine pyrethrum spray collections in dwellings, cattle-baited net and hut trap collections, window trap collections, and larval mosquito surveys are conducted in malarious districts at pre-determined sentinel sites. Susceptibility tests and bio assays detect evidence of insecticide resistance. Data obtained from these tests are used in planning IRS and in ITN/LLIN distribution. Since 2008, TEDHA has also conducted entomological surveillance in its target districts.

Entomological surveillance in Sri Lanka serves two major purposes – it is part of the epidemic forecasting system and is also an essential component of the national integrated vector management (IVM) strategy [49]. IVM is used as a management tool in Sri Lanka and has been successful in agricultural areas through a combination of IRS, ITNs/LLINs, and larviciding and has contributed to the reduction in incidence. IVM in Sri Lanka brings together relevant sectors, community engagement and vector surveillance research to inform the use of insecticides and to determine the most appropriate mix of vector control interventions, environmental management and larval control. IVM in Sri Lanka began in the 1970s, when the hydroelectric and irrigation development project of Mahaweli River led to increases in malaria transmission [50]. Vector control and larval source management were used in response, with participation of communities and with involvement of the irrigation and agriculture sectors [50,51]. In the late 2000s, Farmer Field Schools were used as a platform to make the connection between vector control for health and agriculture, educating farmers about the relationship between public health and agriculture, and involving them in vector management activities [52].

3.4.8 Indoor residual spraying

Indoor residual spraying (IRS) was introduced in 1945 and became the primary vector control tool in Sri Lanka, where perennial spraying targeted all households in malarious districts. Following WHO recommendations issued in the mid-1990s [53], the AMC Directorate initiated a targeted spraying programme, focusing on historical areas of transmission, higher proportion of *P. falciparum*, chloroquine-resistant confirmed infections, and proximity to vector breeding sites [54]. A spatial mosaic insecticide rotation was then implemented in 1998, using a combination of up to six insecticides of two classes, organophosphates and pyrethroids. For example, in 2004, one zone of Kurunegala District applied Fenitrothion (organophosphate), while a neighboring sub-district used Cyfluthrin (pyrethroid). This spatial insecticide rotation has continued to today, unless there are delays in delivery of IRS supplies. The AMC instituted case-based and focal outbreak spraying in 2008, as a result of declining incidence.

In 1975 DDT was replaced by Malathion as reports of resistance to DDT increased. The first synthetic pyrethroid, Lambda-cyhalothrin, was introduced in 1994 and other new insecticides followed. The pyrethroid introduction may have increased community acceptance, which was already considered high (90% found in one study area for Malathion), as they emit less odor and do not leave visible residue on house walls [55,56]. In 2002, Malathion was taken out of use because of mounting evidence of resistance.

National IRS coverage (estimated coverage of the population at risk) fluctuated over the 15-year period, from 64.8% (1995) to 46.5% (2000), then back down to 22.5% in 2005. In 2008, with the declining API there was a shift to case-based and focal outbreak IRS. By 2010, national coverage was down to 5.9% of the population at risk.

Conflict zone

The AMC Directorate conducted IRS in conflict and LTTE-controlled districts, notwithstanding the challenges, including risk of landmines. LTTE personnel assured the AMC Directorate that support would be given to malaria control measures in their zones – partly because their combatants were severely affected by malaria. RMOs in neighboring stable districts report that they assisted conflict districts throughout all years by coordinating IRS along and at times over the border. The government sent supplies, including insecticides, to conflict districts by requesting permission from the Ministry of Defense to send shipments via the sole accessible road to the northeast or, alternatively, by passenger ship. LTTE and AMC Directorate communication increased during the ceasefire period, from 2002 to 2006. It is likely that supply delivery became easier during this period of relative calm.

This communication and collaboration allowed for the continuation of IRS in the conflict zone. In 1995, the population at risk protected by IRS reached 23.5% in the conflict districts, while higher coverage of 79.6% was estimated for non-conflict districts. However, the population at risk protected in conflict districts increased to 52.2% (2000) and 45.9% (2005). This was a higher level of coverage than in non-conflict districts in 2000 (43.7%) and 2005 (10.9%).

3.4.9 Insecticide-treated nets

The second primary vector control tool in Sri Lanka after IRS is the distribution of ITNs and LLINs. ITNs were distributed since 1999 and LLINs were introduced in 2004 with support from the Global Fund. Non-conflict districts were prioritized for ITN/LLIN distribution according to several factors: *P. falciparum* percentage in the past three years, mortality, number of pregnant women and children affected by malaria, proximity to a mosquito breeding site, and presence of internally displaced persons (IDPs) or migrant populations. Because security conditions changed frequently in conflict zones with associated displacement of populations, there was no formal stratification process for ITN/LLIN distribution.

In 2005, 14.8% of the population at risk was estimated to be covered by a LLIN, rising to 22.7% by 2009 and to 34.6% in 2010. Coverage estimates are based on an average three-year lifespan of an effective LLIN and assumes appropriate use. A study conducted in 2008 on use of LLINs found that a range of 89.6% to 90.9% of respondents slept under a LLIN [57].

Conflict zone

ITNs/LLINs were a key tool in conflict districts because of their higher caseloads, IDPs, and logistical challenges in conducting IRS. The Global Fund Round 1 grant supported the distribution of LLINs in conflict districts. The Ministry of Health, as part of the Global Fund grants, collaborated with a Sri Lankan NGO, Lanka Jatika Sarvodaya Shramadana Sangamaya (Sarvodaya), in the distribution of LLINs in northern conflict districts. The United Nations Children’s Fund (UNICEF) and WHO also distributed LLINs. Through this network, 38.1% of the population at risk in conflict districts was covered by an LLIN in 2005, and 3.3% were covered in non-conflict districts. By 2009 coverage was similar in conflict districts (40.9%) and had increased in non-conflict districts (19.1%).

3.4.10 Treatment and prophylaxis

Since the mid-1990s, it was recommended that all fever patients were to be tested for malaria. Since 2007, testing is recommended only for fever cases with malaria-related history and symptoms - body aches, joint pain, headache, nausea, vomiting, or diarrhea.

Sri Lanka has a national health service, and consultation and treatment are provided free at all public hospitals. Global Fund support allowed for the scale-up of diagnosis and treatment of malaria. In addition, travelers to endemic countries receive free chemoprophylaxis for up to three months, based on destination of travel.

From the mid-1990s until 2006, chloroquine and primaquine (0.25 mg/kg/day for adults), with a five-day regimen in endemic areas and 14 days in low transmission areas, was used for *P. vivax.* To ensure radical cure, or parasite clearance from both the blood and liver stages, a mandatory 14-day primaquine course was extended nationwide in 2006 [58]. Prevalence of Glucose-6-phosphate-dehydrogenase (G6PD) deficiency is relatively low (range of 1%-3%) [59]. Patients are not routinely screened for G6PD deficiency before treatment.

In 1999, it was estimated that 51% of *P. falciparum* infections were resistant to chloroquine, and by 2004 several cases of resistance to sulphadoxine-pyremethamine were detected [58]. As part of the malaria elimination strategy and as a result of an increased number of imported *P. falciparum* infections, artemisinin-based combination therapy (ACT), artemether-lumefantrin, was introduced in 2008. Primaquine for treatment of the gametocyte stage of the parasite has been documented to have been used in Sri Lanka since 1956 or earlier [3]. The National Treatment Guidelines recommend that all *P. falciparum* patients are admitted for three days, and *P. vivax* patients should receive follow-up visits to ensure compliance with the primaquine regimen [60].

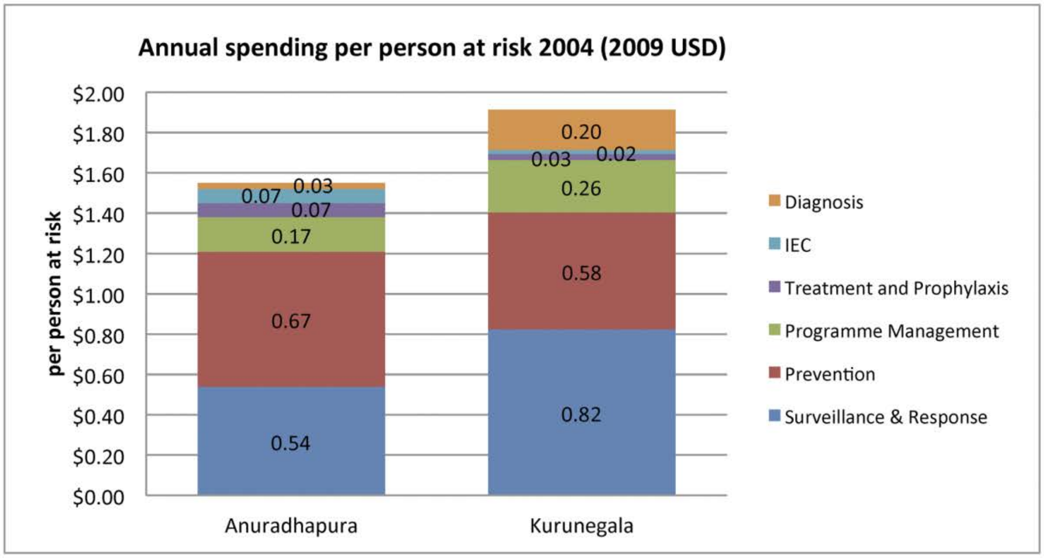
While reports in the early 1990s indicated that self-treatment was common [59], more recent studies describe a low level of self-treatment for malaria and patient preference for confirmed diagnosis [61-63].

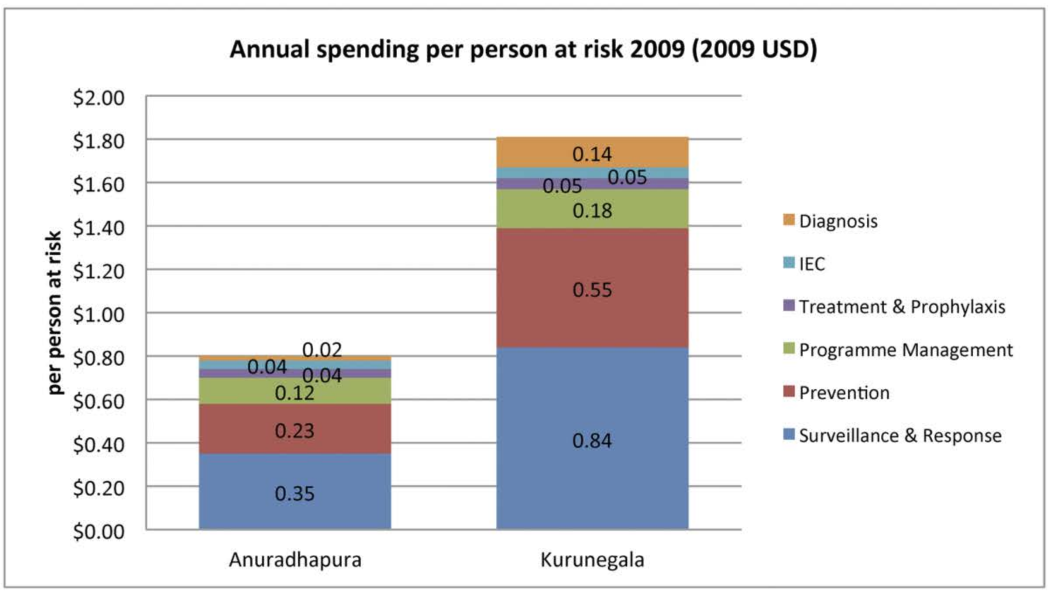
3.4.11 Cost of malaria control and elimination

The Sri Lankan government and the Global Fund were and currently are the main sources of funding for malaria control in Sri Lanka. Funding for malaria control at the district level, based on risk and available resources, is allocated by the Ministries of Finance and Health. Sri Lanka successfully applied for and received funding for its malaria programme from the Global Fund in Rounds 1, 4, and 8. The approved grant amount was US $7.3 million in Round 1, $3.7 million in Round 4, and $21.6 million in Phase 1 of Round 8. The AMC Directorate, in collaboration with the Ministry of Health and the Global Fund Country Coordinating Mechanism Sri Lanka, determines which districts to include in grant proposals. Of the two districts selected for detailed costing studies, Anuradhapura received Global Fund support in Rounds 1 and 8, and Kurunegala in Rounds 4 and 8. WHO and World Bank/IDA provided additional support, which is only partially represented in the expenditure data. Both of these districts are located outside of the previous conflict zone, where major investments are targeted to scale up surveillance under the Global Fund Round 8 grant.

From 2004 to 2009, Anuradhapura District reported a decline of 48% in malaria programme expenditure per person at risk (Figure 3.6). Expenditures in Kurunegala District did not significantly change.

Figure 3.6: Costs per person at risk in 2004 and 2009 by intervention category, in $USD, two districts





From 2004 to 2009, there were also differences between Anuradhapura and Kurunegala in the proportion of total expenditure allocated to programme components. The proportion allocated for prevention declined in Anuradhapura from 2004 to 2009 (43.6% to 29.1%), while the percentage for surveillance slightly increased. In contrast, the proportion of malaria expenditures in Kurunegala on prevention and surveillance measures stayed consistent over these years.

The proportion of total expenditure distributed across cost categories (e.g., consumables) shifted from 2004 to 2009 for both districts. Anuradhapura reported a slight decrease in proportion of expenditure on personnel from 2004 to 2009 (80.8% to 74.0%) while Kurunegala reported an increase in the proportion for personnel (48.3% to 67.5%). Nationally, malaria full-time employees decreased by 29% during this period, from 2,991 to 2,113 [64].

Initial cost estimates for elimination of *P. falciparum* and *P. vivax* in Sri Lanka, according to the five-year Global Fund Round 8 proposal budget projections, is $1 USD per person and $5 per person at risk [65].

3.5 Discussion

3.5.1 Principal findings

From 1999 to 2011, Sri Lanka achieved a 99.9% reduction in confirmed infections. API rapidly declined from 1999 (22.1) to less than 1 in 2004. Cases thereafter remained low, a trend found even during the post-tsunami period and more recently through PCR assay [39,41,42]. Deaths attributed to malaria also declined after 1998, with zero indigenous deaths since 2008.

As total malaria cases declined, the proportion caused by *P. vivax* increased. This trend has been identified in other countries with a declining malaria transmission [66], and may be linked to the successful treatment and vector control strategies that lower the *P. falciparum* burden faster than *P. vivax* [66,67]. *P. vivax* is more challenging than *P. falciparum* to eliminate due to more asymptomatic and subclinical infections, infections at lower parasite densities making detection more difficult, the ability of the parasite cycle in the vector to exist at lower temperatures, and the existence of hypnozoites, the dormant liver stage that causes relapses. In addition, a 14-day treatment regimen with primaquine is required to kill hypnozoites. This radical cure of *P. vivax* complicates treatment adherence and has the side effect of hemolysis in some patients deficient with the G6PD enzyme [68]. A second trend seen in Sri Lanka is the substantial increase in proportion of malaria cases in adult males. This trend is related to a higher level of exposure in males of particular professions to infected vectors. In Sri Lanka, these at-risk populations tend to be gem miners and security personnel that work in remote jungle areas where access to medical treatment is difficult and use of preventive measures, such as domicile-based vector control methods, is more challenging.

The Anti-Malaria Campaign benefits from a long-running history rich in technical malaria control and elimination experience. The AMC, bolstered by external funding and partnerships with Sri Lankan and international NGOs, drove the decline through adaptation of innovative, evidence-based strategies of vector control, surveillance, and case management. IVM involved multiple sectors and communities in vector control, especially agricultural and irrigation sectors. IRS remained the primary vector control tool throughout the years, with new methods employed as they became available. The introduction of spatial mosaic insecticide rotation and new insecticide classes may have contributed to the effectiveness and acceptability of IRS. Coverage was maintained nationally.

The introduction of ITNs and, more recently, LLINs may have contributed to maintenance of low transmission by targeting areas with high transmission and hard-to-reach populations that may not have access to IRS. Collaborations with Sarvodaya, UNICEF, WHO and other partners made this distribution possible.

A strong passive case detection system, with a focus on malaria diagnosis and treatment through the APCD system, identifies the majority of malaria infections. Although coverage is relatively low, ACD is believed to help reduce the magnitude of peaks during transmission seasons by identifying both asymptomatic and symptomatic infections. Increased diagnostic capacity across the country over this period helped to sustain surveillance. The introduction of ACT and primaquine for *P. falciparum* and 14-day primaquine treatment for radical cure of *P. vivax* may have contributed to preventing onward transmission [67,69].

Vector control and surveillance measures were maintained and at times scaled up more rapidly in districts having active conflict from 1995 to 2009. IRS was continued with support of government funding and LLINs were distributed to these areas through external funding and strong NGO partnerships. Starting in mid-2000, the annual rate of blood examination (ABER) was higher in the conflict areas. Targeted ACD increased access of remote populations to diagnosis and treatment and provided facilities to those whose health care infrastructure was damaged by conflict.

As the country moved from high endemicity in 2004 to controlled-low endemic transmission in 2009, Anuradhapura District reported a 48% reduction in expenditure. This decline may in part be due to decreases in external funding and to decreases in the scale of IRS activities. Increases in cost for elimination as compared to controlled low-endemic malaria were estimated for China, Mauritius, Swaziland, Tanzania-Zanzibar [70] and India [71], and Sri Lanka will likely have a similar experience. These costs will be extremely sensitive to the rate of importation and the degree to which costs can be shared with dengue and other vector-borne disease control efforts.

This case study adds to the growing body of literature that describes successful strategies to reduce malaria burden. Sri Lanka shares a number of success factors with other countries that have successfully reduced their burden, such as Bhutan, Brazil, Eritrea, India, and Vietnam, and with countries such as Mauritius who have successfully eliminated [72-74]. Bhutan, a fellow eliminating country, has seen a similar decline in cases, as well as an increase in the proportion of infections in adult males and in those caused by *P. vivax*. Bhutan and Sri Lanka both increased access to health services in a period of economic development, both of which likely contributed to success in driving down malaria. Both countries sustained malaria interventions, such as improved case management and vector control through IRS and LLIN. Similar to Brazil, Eritrea, India and Vietnam, Sri Lanka has a decentralized health system, yet the AMC Directorate maintains strong technical leadership of the programme. Sri Lanka also has had pockets of high transmission and maintained a similar approach, focusing on case management while introducing evidence-based prevention measures and further targeting of IRS. In financing, the country has benefited from World Bank funding and, more recently, Global Fund inputs which have assisted the country in providing the best intervention mix. The history of malaria elimination in Mauritius echoes the resurgence that occurred in Sri Lanka in 1963. Mauritius successfully eliminated malaria in 1998 for a second time, and has put significant resources toward maintaining malaria-free status. The Mauritius experience provides lessons for Sri Lanka and other eliminating countries.

In contrast to these countries, however, Sri Lanka achieved success despite having had a major long-running civil conflict. This success has been seen in a handful of other countries, such as in Afghanistan, Iraq, and Timor Leste [75,76]. Timor Leste, similar to Sri Lanka, sustained malaria control in populations affected by war. Both countries adapted to the changing context and conducted case management and vector control measures at a scale large enough to avoid major outbreaks. The Sri Lanka case study shows that progress towards elimination can be achieved in conflict settings by maintaining malaria prevention and surveillance measures in conflict zones.

3.5.2 Limitations

This case study relies upon national surveillance data to identify trends in malaria epidemiology. This case study did not include measures that estimate the number of infections that were unreported or in those that did not seek treatment.

Data from local and international NGOs or private clinics that participated in malaria control, prevention, diagnosis and treatment were not represented in this case study. Likewise, the costing analysis did not account for expenditures through non-governmental channels, or private expenditures by households. Costing data was collected and analyzed from a small sample of two districts and while the costs cannot reflect those of the entire country, they provide a basis for comparison across phases in the same district and may serve as a comparison against each other. An estimate for the cost of elimination was found in a previous analysis, which was based on budget projections, not expenditure data.

The interviews were conducted through a purposeful sampling methodology, with initial contacts supplied by the programme manager. There may be selection bias in the results of these interviews as a result of this selection process. However, the case study includes a wide range of positions and experiences in the interview participants, from programme managers to technical officers to IRS spraymen. This range is important to capture in order to reflect experience from decision-makers to those closest to the work.

3.5.3 The way forward

Sri Lanka is working to eliminate malaria by the end of 2014 using surveillance, reporting, radical cure, rapid case response and case follow-up, and the management of imported malaria. In order to develop and implement effective strategies for elimination and prevention of reintroduction, countries such as Sri Lanka would benefit from further documentation of successful strategies, in particular around maintaining robust and efficient surveillance and response systems and engaging other sectors. Most importantly, Sri Lanka must continue to identify and treat imported malaria infections [77]. The risk of importation is likely to increase each year. Tourism revenues increased from 2009 to 2010 by 38% [25,78]. Even more importantly, large ferry services have restarted from Tamil Nadu, India, to Colombo and smaller boat traffic between the countries is likely to increase in the coming years [79].

Also of importance is the assurance of long-term, sustainable funding. The recent cancellation of Round 11 from the Global Fund shows that support for malaria programmes, in particular low-burden countries, is at risk [80]. Reductions in funding contributed to the devastating resurgence in Sri Lanka in the 1960s and a repetition of this history must be avoided. A case must be made for continuing investment in Sri Lanka and in other low-endemic and elimination settings. Countries can better state this case if armed with high-quality cost estimates of elimination and prevention of reintroduction. Comprehensive cost-benefit analyses using a macro-economic framework [81], taking into account well-described and quantified benefits [8], will enhance this argument.

3.6 Acknowledgements

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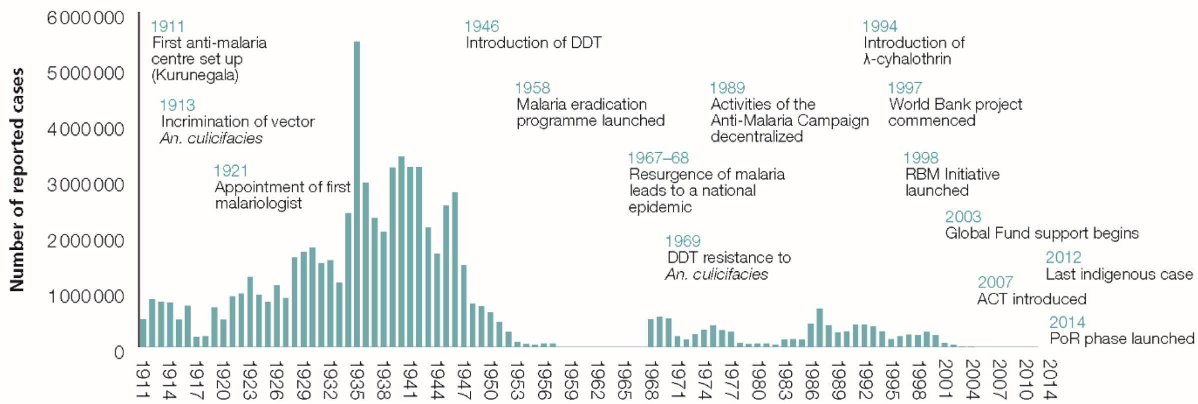
3.8 Postscript to the Sri Lanka Case-Study (2012-2017)

In 2012, the publication year of the Sri Lanka case-study, the Sri Lanka Anti-Malaria Campaign recorded its last indigenous cases, and in 2014 launched its Prevention of Reintroduction (POR) campaign (Figure 3.7) [1]. After holding the line at zero indigenous cases for three full years, the WHO announced that Sri Lanka was certified as malaria free on September 5, 2016 [2].

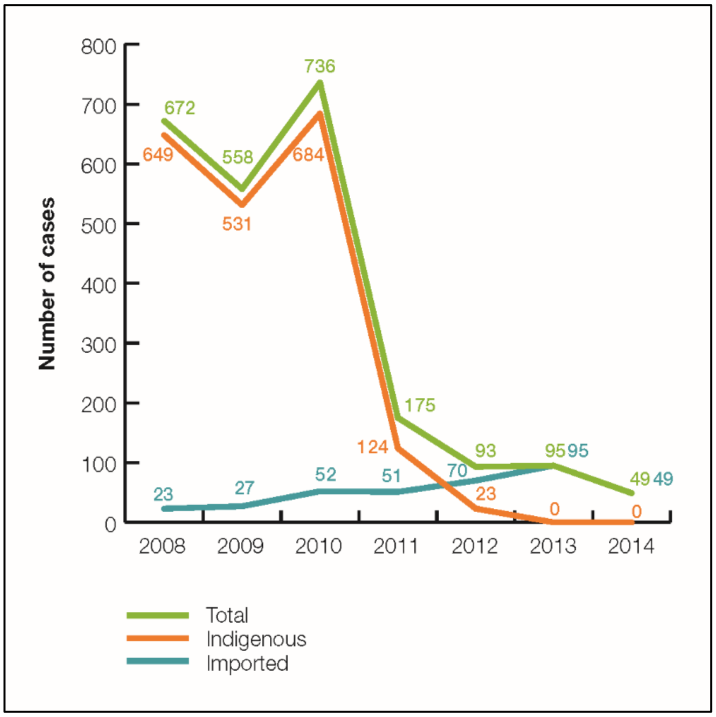
Figure 3.7. Historical timeline of malaria control in Sri Lanka, 1911-2014 (from "Maintaining zero: An update to the Sri Lanka malaria elimination case study," 2014) [1]



ACT, artemisinin-based combined therapies; PoR, prevention of re-introduction

The last indigenous cases were found in the northern and southern regions of the country (Figure 3.7) [1]. Although indigenous cases were reduced to zero, imported cases were still found, and in fact they rose from 70 cases in 2012 to 95 in 2013, then declined to 49 cases in 2014 (Figure 3.8) [1]. They are considered a major risk to maintaining elimination in Sri Lanka.

Figure 3.8. Reported malaria cases in Sri Lanka, 2008-2013 (from "Maintaining zero: An update to the Sri Lanka malaria elimination case study," 2014) [1]



The majority of imported cases in 2013 were in Sri Lankans who were returning from overseas travels, and there was one report detailing an increase in Sri Lankan "irregular" migrants, or those without legal status in their host country, who returned from malaria endemic countries (mainly West Africa) [1,3]. Irregular migration increased after the end of the civil conflict in Sri Lanka, in 2009. Importation of malaria also occurs because due to re-entry into Sri Lanka from overseas military duties, such as Sri Lankans serving U.N. peacekeeping missions in Haiti or Liberia [4]. Imported infections in non-Sri Lankans were mainly tourists and asylum seekers [1].

Importation is a major risk for the country because receptivity to malaria in the areas of the country that used to be malaria endemic remains high as the vector is still present [5]. An added risk is that the communities in these areas have likely lost some immunity to malaria over time. Because of this importation risk, the Anti-Malaria Campaign has invested additional resources to boost surveillance, to detect all imported cases and to ensure rapid response to all types of cases, including follow up of each individual case [1, 6]. Screening programs, which are voluntary or mandatory, are many times done through collabrations (e.g., with UN Agencies, port authorities). The programme also seeks to sustain entomological surveillance activities but through streamlining and reducing costs to be more effective and targeted [1].

Another major risk for elimination in the country is considered to be diagnostic uptake. The number of severe malaria cases has increased as a result of delayed diagnosis and treatment. Clinics do not immediately consider the possibility of and test for malaria when presented with a febrile patient [1,5,7]. The AMC has conducted training programs for clinics to lower the risk of delayed diagnosis. Engaging the private sector in this training and in reporting of cases has also been a challenge. The AMC has revised treatment guidelines to include a stat dose of 0.75 mg/kg bodyweight of primaquine to eliminate gametocytes for all cases of *P. falciparum* pre-discharge from the hospital, in an effort to reduce the possibility of transmission [1].

The AMC seeks to maintain adequate human resources and capacity in order to effectively respond in the case of an outbreak or resurgence [1]. One consideration of this is the ability for the AMC to maintain an element of verticality in its malaria programme operations, having learned from the dismantling of its leprosy programme that it poses a risk to successful elimination [7]. Another component of this plan is to maintain buffer stocks of LLINs and insecticides for IRS in case of an outbreak [1].

3.9 References for Postscript

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CHAPTER 4

Malaria control in Bhutan: a case study of a country embarking on elimination

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4.1 Abstract

Background: Bhutan has achieved a major reduction in malaria incidence amid multiple challenges. This case study seeks to characterize the Bhutan malaria control programme over the last 10 years. Methods: A review of the malaria epidemiology, control strategies, and elimination strategies employed in Bhutan was carried out through a literature review of peer-reviewed and grey national and international literature with the addition of reviewing the surveillance and vector control records of the Bhutan Vector-Borne Disease Control Programme (VDCP). Data triangulation was used to identify trends in epidemiology and key strategies and interventions through analysis of the VDCP surveillance and programme records and the literature review. Enabling and challenging factors were identified through analysis of socio-economic and health indicators, corroborated through a review of national and international reports and peer-review articles. Findings: Confirmed malaria cases in Bhutan declined by 98.7% from 1994 to 2010. The majority of indigenous cases were due to *Plasmodium vivax* (59.9%) and adult males are most at-risk of malaria. Imported cases, or those in foreign nationals, varied over the years, reaching 21.8% of all confirmed cases in 2006. Strategies implemented by the VDCP are likely to be related to the decline in cases over the last 10 years. Access to malaria diagnosis in treatment was expanded throughout the country and evidence-based case management, including the introduction of artemisinin-based combination therapy

(ACT) for *P. falciparum*, increasing coverage of high risk areas with Indoor Residual Spraying, insecticide-treated bed nets, and long-lasting insecticidal nets are likely to have contributed to the decline alongside enabling factors such as economic development and increasing access to health services. Conclusion: Bhutan has made significant strides towards elimination and has adopted a goal of national elimination. A major challenge in the future will be prevention and management of imported malaria infections from neighbouring Indian states. Bhutan plans to implement screening at border points to prevent importation of malaria and to targeted prevention and surveillance efforts towards at-risk Bhutanese and migrant workers in construction sites.

4.2 Background

In recent years, there has been substantial progress made in reducing the malaria burden around the globe [1,2]. From the deep Amazon and the coastal plains of East Africa to the Malaysian peninsula, incidence has been decreasing over the last decade, related to increased resources for malaria control and better access to new and improved tools [3,4]. The South-East Asia region has some of the most pronounced declines, with five countries out of 11 reporting decreases of more than 50% of cases from 2000 to 2009 [2]. One of these success stories is tucked away, high up in the eastern Himalayas: Bhutan has achieved remarkable success in bringing down malaria transmission and announced a national strategy to eliminate malaria by 2016.

The progress made in Bhutan in the last 10 years is remarkable given the major challenges it faces. The country is placed in some of the most difficult terrain in the region, where landslides create impassible roads in the monsoon months and where 21% of households are located more than a four hour walk from the nearest road [5]. The low-lying southern region of Bhutan is at high-risk for malaria transmission [6] and has a highly porous border with India, through which there is significant population movement. In addition, large numbers of migrant workers enter the country to work in large-scale development projects in areas vulnerable to malaria transmission, creating a risk of continual importation and re-introduction of malaria into the area [7]. Given these and other challenges, the recent success in reducing malaria incidence may contain lessons for other countries [8].

This paper seeks to characterize the malaria programme of Bhutan over the last 10 years, exploring trends in the epidemiology of malaria, malaria control strategies and interventions, and the enabling and challenging conditions of Bhutan with emphasis on the endemic southern border and population migration.

4.3 Methods

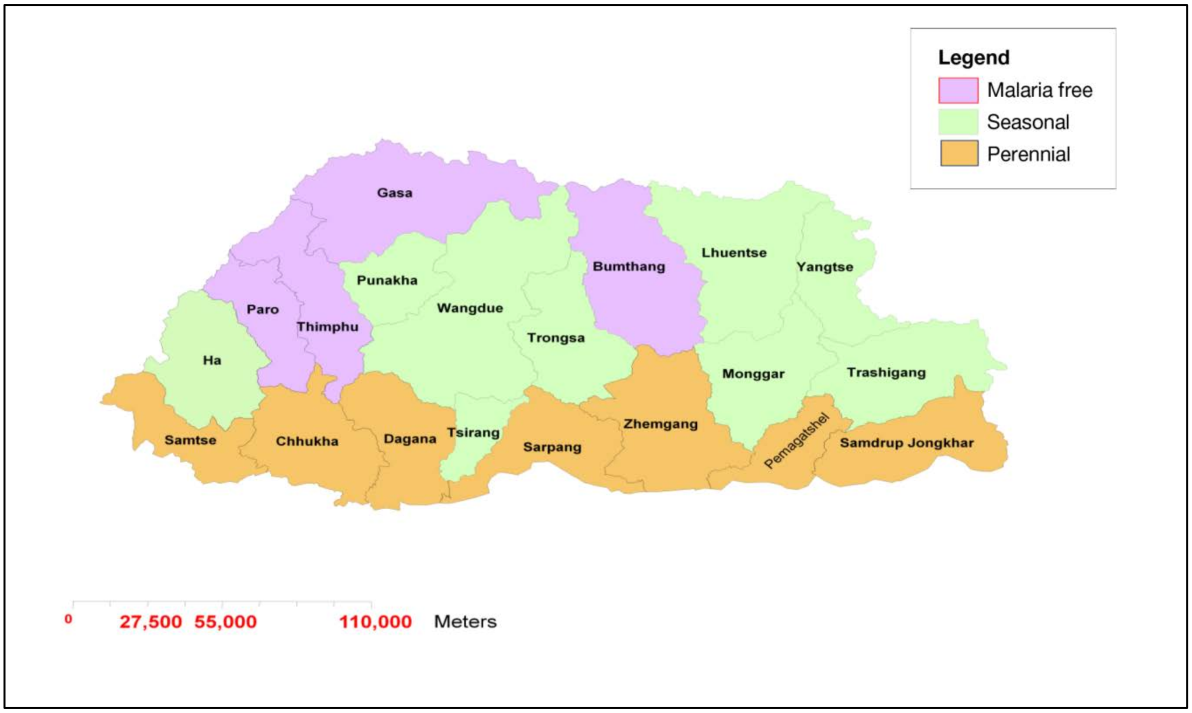
4.3.1 Geography, population and climate

The Royal Government of Bhutan is a small country, spanning 38,394 km2, with a population of 677,343 bordered in the north by the Tibetan Region of China, and by India to the west, south and east with the states of Sikkim, West Bengal, Assam, and Arunachal Pradesh, respectively. The country is mainly mountainous, rising to a maximum elevation of 7,314 m and extending down to as low as 160 m above mean sea level in the southern foothills. Bhutan's economy is based on agriculture, forestry, and hydropower electricity exports to India [9,10].

Bhutan has seasonal rainfall with monsoon rains occurring from June to September, when most malaria cases occur [11]. A winter northeast monsoon occurs from November to March, with snowfall in the higher elevations. Bhutan has only 2.3% arable land, most of which is in the west [10].

Malaria risk areas are mainly forest and forest-fringe human settlements, in particular those with irrigation or development projects, such as hydropower project sites [5]. Twenty-four percent of the population lives in areas considered free of malaria, located in four districts in the north-east and central part of the country (Figure 4.1) [12]. These areas are not receptive to malaria transmission due to their high elevation and cooler temperatures. Indigenous cases reported from these districts are imported cases from other districts. Nine districts in a band running east to west across the center of the country are considered at risk for seasonal transmission, having a history of local transmission although some of them have not had an indigenous case in the last three years. This zone contains 34% of the population. Seven districts, with a population of 284,512 (42% of the total population), are considered malaria-endemic, where transmission occurs throughout the year [11]. These districts border the Indian states of Assam and West Bengal.

Figure 4.1: Prevalence of malaria in Bhutan. Districts in purple are malaria-free, districts in green are considered at risk for seasonal transmission, districts in brown are considered malaria-endemic



4.3.2 Programme data

A literature review was conducted using PubMed, Google Scholar, Google, SpringerLink [13], World Health Organization (WHO) South–East Asia Region Institutional Repository [14], World Health Organization Library Database (WHOLIS) [15], and through requests to the WHO Archives at the WHO Headquarters in Switzerland. Search terms were “Bhutan” AND “malaria” OR “prevention” OR “refugee” OR “Nepal” OR “India” OR “supply, supply system” OR “health system” OR “health supply.”

Routine national health facility surveillance data were collected and reviewed in-country by two researchers (TY and CSG), for indigenous (cases contracted locally) and imported cases [16]. In Bhutan, an imported case is a confirmed malaria infection in any foreign national. The reported cases described in this study were confirmed by microscopy. Reporting of presumptive cases is not the policy in Bhutan and rapid diagnostic test (RDT) results are cross checked by microscopy. Results of the microscopy confirmation process are reported, not the RDT results. These secondary data were collected from the Vector-borne Disease Control Programme (VDCP) headquarters in Gelephu, which receives and compiles reports of confirmed cases from the districts. Other data collected were VDCP-derived estimates of population at risk and distribution and coverage of long-lasting insecticidal net (LLIN), insecticide-treated bed nets (ITN), and Indoor Residual Spray (IRS). Annual rainfall data were collected by the VDCP for the period 1996–2010 for 18 districts. When discrepancies between any of the data sources were found, follow-up information was sought from district offices by the VDCP programme manager (TY).

4.3.3 Data analysis

Surveillance and vector control data were plotted using Microsoft Excel and trends were observed. These trends were then compared with those described in the literature identified in the review and with information provided by the VDCP headquarters and district officers, using data triangulation to identify and confirm trends [17]. The WHO World Malaria Report surveillance data were used to corroborate the VDCP data records.

4.3.4 Ethical considerations

The Ministry of Health in Bhutan approved the conduct of the case study. Data from the Ministry of Health, Vector-Borne Disease Control Programme were analysed in aggregate form.

4.4 Findings

4.4.1 Literature review

The literature review identified 35 peer-review publications, 28 WHO reports and documents, ten reports by other partners and agencies, and 20 published or grey reports from Bhutanese ministries including three reports from the Ministry of Health. A list of these documents is shown in the online web appendix (Additional file 1) [18]. These documents provided programmatic information and corroborated the findings of the data analysis. The Malaria Programme Reviews, conducted in collaboration with WHO by the VDCP in 2007 and 2010, were key sources for this case study [12,19].

4.4.2 Programme structure

The VDCP of Bhutan coordinates and ensures the capacity of the district health teams to carry out prevention of malaria and other vector-borne diseases, namely dengue, kala-azar and Japanese encephalitis. The VDCP relies upon the structure of the national health system of Bhutan to provide the integral components of malaria surveillance, case management, and prevention through an integrated community health approach [20]. The national primary health care system is comprised of national and regional referral hospitals, district hospitals, Basic Health Units (BHUs) and Outreach Clinics (ORC). Outreach clinics conduct antenatal check-ups and immunizations, but do not play a major role in malaria control.

The service delivery structure of the VDCP is based upon multipurpose malaria health workers, termed malaria technicians, that are deployed by the VDCP to hospitals, and in the endemic southern districts, BHUs as well [12]. These health workers, whose salary is paid by the Ministry of Health, work only on malaria and provide a wide range of services including reading blood slides for malaria diagnosis, issuing treatment, case reporting, and case follow-up. They also support IRS and LLIN distribution, entomological surveillance, and Information Education and

Communication (IEC) activities. Health assistants, nurses and doctors provide the malaria treatment. Village health workers help in executing IEC activities. Spray operators conduct the IRS coordinated by the malaria technicians.

The role of malaria technicians has begun to be integrated with other vector-borne diseases beyond malaria control, and a new title has been assigned—“Medical Technicians.” In the future it is expected that the role of Malaria Technicians will increasingly become integrated and their main activities may change, posing a risk of diminishing vigilance for malaria as other diseases become a greater priority. However, as of yet, only a portion of them received the integration training and many are still referred to as “Malaria Technicians”.

Domestic resources, through tax and non-tax revenue of the Government of Bhutan, account for two-thirds of total health-related expenditures in Bhutan, and external financing accounts for approximately one-third [21]. The Royal Government of Bhutan has provided an increasing amount of support to the VDCP over the last 5 years, contributing 21.5% of the total VDCP budget over the period 2009–2010. The total VDCP budget was $445,950 USD in 2009–2010, which included malaria and other vector-borne diseases. Government support to district malaria-related expenditures are not included in this figure.

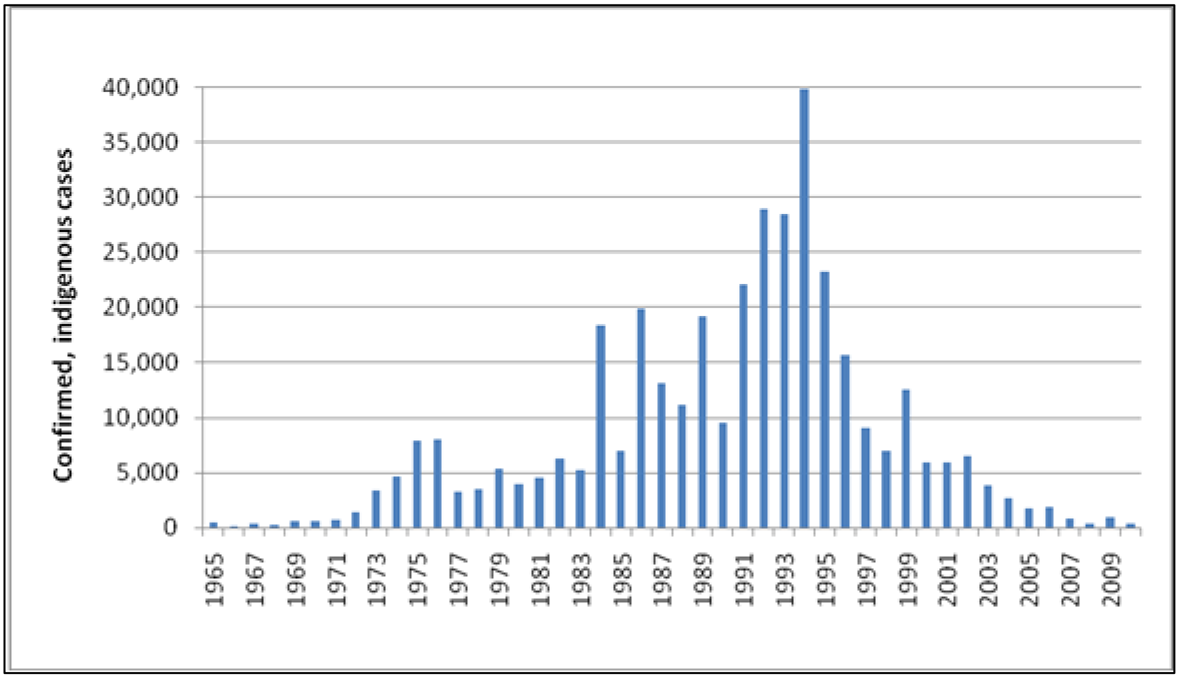
The Government of India, a long-time partner of the Royal Government of Bhutan, has contributed USD $177,777 annually, which is mainly used to procure insecticides for Bhutan’s IRS programme. This collaboration has continued since the 1960s. Approved Global Fund to Fight AIDS, Tuberculosis and Malaria (Global Fund) grant amounts were $1,737,190 (Round 4, funding received starting in 2005) and $2,662,468 (Round 7, funding began 2008) [22]. In addition, the World Health Organization (WHO) and other partners have provided technical assistance and some financial support. Out of ten countries in the South–East Asia region, Bhutan ranks the highest in cumulative per person availability of donor funding, at $10.75 USD per capita [22].

4.4.3 Epidemiology of malaria

Locally contracted or indigenous cases. In 2010, there were 436 microscopy-confirmed indigenous cases. Of these, 261 (59.9%) were due to *Plasmodium vivax*, 140 (32.1%) were due to *Plasmodium falciparum*, and 35 (8.0%) were mixed infections. The total number of cases in 2010 is similar to the 518 cases reported in 1965 (see Figure 4.2) [11]. All reported cases are confirmed by microscopy, even if the initial diagnosis was by RDT. Bivalent RDTs to detect both *P. falciparum* and *P. vivax* were introduced in 2006.

The highest peak of malaria cases occurred in 1994, with nearly 40,000 indigenous cases. A major decline of 85.1% occurred from 1994 (39,852 cases) to 2000 (5,935) that continued until 2010 (436 cases). A small increase in cases occurred from 2008 (329) to 2009 (972), which was associated with the early arrival of the monsoon rains or the loss of efficacy of LLINs distributed in 2006 after a lapse of 3 years [23]. The Annual Blood Examination Rate (ABER), or the number of blood slides examined for malaria parasites as a proportion of the total population at risk, varied over the years with no clear trend and ranged between 9.7% (2008) and 20.9% (2010).

Figure 4.2: Malaria cases in Bhutan, 1965–2010



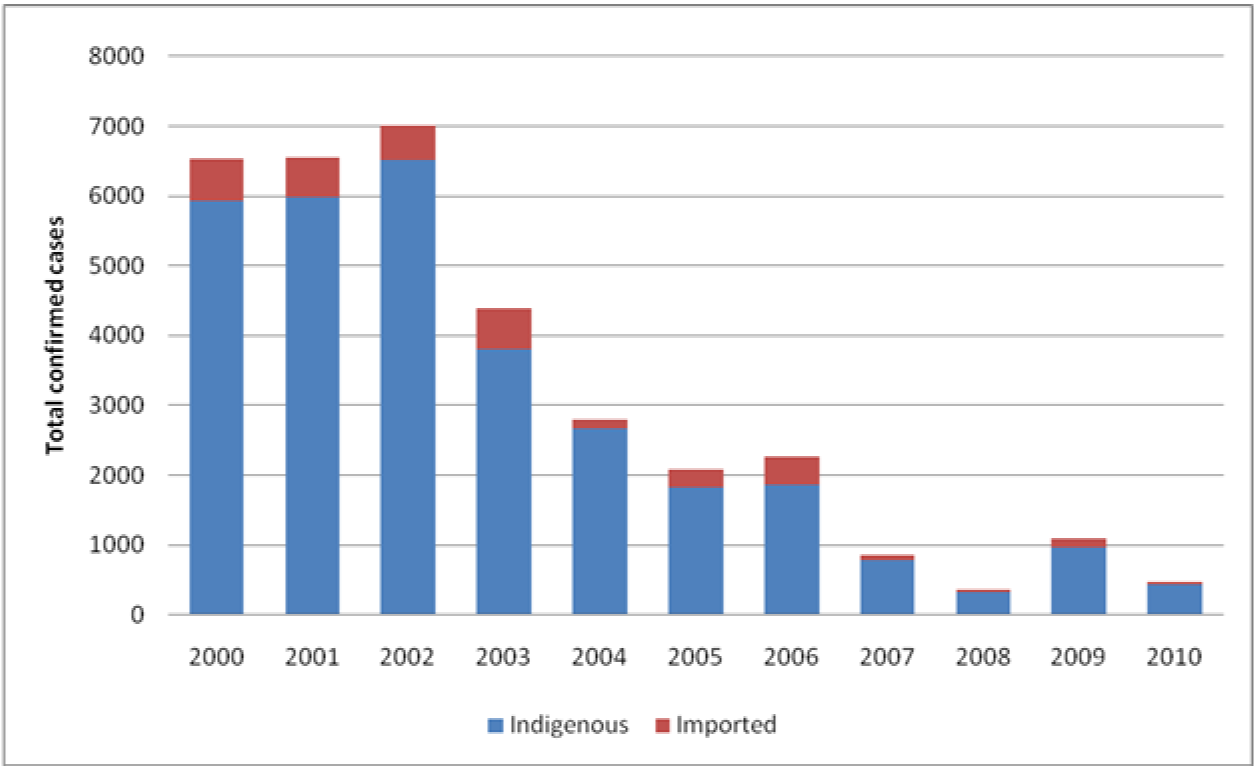
The proportion of indigenous cases resulting from *P. vivax* infections, as compared to those identified as *P. falciparum* or mixed infections (both *P. falciparum* and *P. vivax*), has ranged from a low of 42.5% (2009) to a high of 59.9% (2010). Mixed infections in Bhutanese have nearly doubled from 2001 to 2010, from 4.4 to 8.0%, respectively. This increase may be related to improvement in diagnostic specificity and is less likely to reflect an increase in transmission intensity of mixed infections.

Males, specifically male farmers and students between the ages of 15–49 years, are the population groups at highest malaria risk [24]. This is most likely due to various occupational factors, such as forest work, firewood collection, guarding fields at night, or travel to India for business [8,12].

Imported cases. The proportion of total cases (indigenous and imported) considered imported, or those found in foreign nationals, varied greatly over the years, reaching a high of 408 imported cases in 2006, representing 21.8% of all confirmed cases (Figure 4.3). In 2010, 28 cases were considered to be imported (6.0% of total confirmed cases).

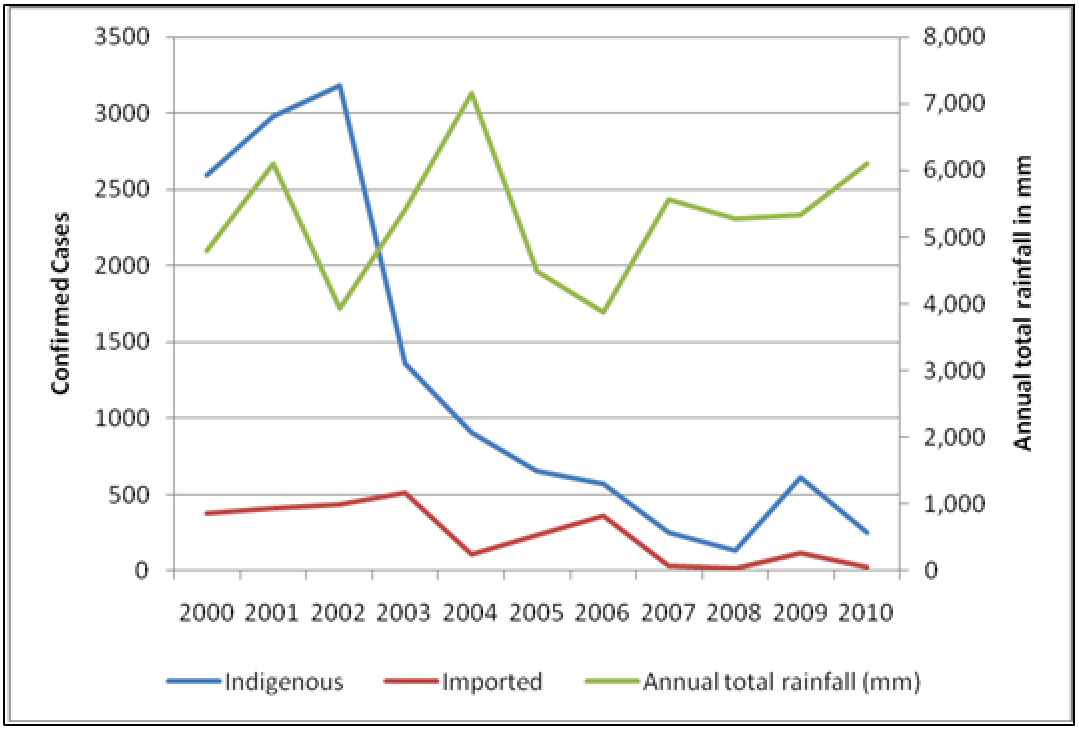
Imported cases have a slightly higher proportion of *P. falciparum* infections: in 2010, 46.4% of all imported infections were due to *P. falciparum* in contrast to 32.1% of indigenous cases. Similar to the increasing trend found in indigenous cases, mixed infections in imported cases appear to be increasing and represented 17.9% of infections in 2010.

Figure 4.3: Confirmed cases in Bhutan, 2000–2010



Sarpang District, which borders Assam State of India, recorded the majority of imported cases (every year from 2000 to 2010) and the highest number of indigenous cases in 7 out of 10 years (2000–03, 2005, 2008–10). Over the last decade, this district has contributed an average of 87.5% of imported cases and an average of 47.1% of indigenous cases in Bhutan. The border is highly porous, exemplified by the many residents of neighboring Assam receiving treatment in the district's health clinics. In 2009 there was a reported outbreak of malaria in Assam with a 26.8% increase in reported cases [23]. This trend was mirrored in Sarpang, where a three-fold increase was reported that same year (Figure 4.4). Eighty percent of infections that year were due to *P. falciparum*. Rainfall trends from 2000 to 2010 from Bhur Station in Sarpang District indicate that there was no clear trend in rainfall in this district over this period (Figure 4.4) [25].

Figure 4.4: Confirmed cases in Sarpang District, indigenous and imported cases, 2000–2010, with total annual rainfall in Sarpang District [25]



Vectors. In the past, *Anopheles minimus* was incriminated in transmitting malaria in Bhutan and it was presumed that *Anopheles fluviatilis* and *Anopheles dirus* were also important vectors (Table 4.1) [26]. However, none of these species have been recorded in the last 10 years. While *Anopheles minimus* and *Anopheles fluviatilis* have been found recently in eastern Bhutan (Bhutan VDCP), *Anopheles pseudowillmori* and *Anopheles culicifacies* are suspected to be the main vectors because of their behaviour (both endo and exo-phagic and anthropophillic) and their relative abundance during the peak transmission season. Both species in high densities have been found to bite cattle between 18:00–20:00 h. Species composition studies undertaken in Bhutan on *Anopheles culicifacies* found species B and C; C is not considered a vector, but B is a proven malaria vector in India [26]. *Anopheles culicifacies* are rarely found indoors in the presence of two rounds of IRS per year and LLIN coverage. Current studies have still failed to incriminate any vectors in Bhutan. Training for sibling-species composition, host-blood meal analyses and techniques for sporozoite infectivity are needed to inform vector control interventions [12].

Table 4.1: Anopheles fauna in Bhutan [26]

Plains: *An. pseudowillmori, An. vagus, An. subpictus, An. culicifacies, An. jamesii, An. pseudojamesii, An. annularis, An. philippinensis*, *An. kochi, An. peditaeniatus*, *An. acinitus*, *An. barbirustris*, *An. barbumbrosus, An.umbrosus*
Mountains: *An. maculatus*, *An. willmori, An. lindesayii, An. baileyii, An. aitkenii and An. bengalensis*

4.4.4 Surveillance

Malaria is a notifiable disease in Bhutan, with microscopy-confirmed cases reported on a weekly basis. As private sector health practice in Bhutan is minimal, malaria under-reporting from this sector is considered negligible [2]. There is a functioning quality control system for microscopy in malaria-endemic areas; compulsory monthly blood film cross-checking is conducted by the VDCP. In at risk seasonal transmission and malaria-free areas, staff members send slides to the VDCP for cross-checking on a quarterly basis. 10% of negative and 50% of all positive slides are cross-checked for accuracy and quality. Malaria microscopy training is ordered if there are false positive or negative rates beyond the acceptable limit. A significant challenge is that blood films are sent by post and are sometimes broken and un-readable upon arrival.

Vertical reporting occurs each week wherein reports flow from health facilities to the districts, then to the VDCP [12]. Reports are submitted to the Bhutan information system of the Ministry of Health each quarter. Reporting is supervised by on-site data verification during monitoring and supervision visits to the health centers. In addition, the VDCP checks with individual centers by phone if there are missing or incomplete reports. The VDCP analyses the weekly and monthly reports and, if an increase in cases is reported, the respective health center is alerted and vector and case surveillance investigation and Information, Education and Communication (IEC) activities are carried out to locate the source of transmission and implement containment strategies, including IRS in the cases where the area has not been sprayed the two rounds that year [24]. Mass screening of fever cases is also conducted within the affected locality (no fixed radius). A team from the VDCP, accompanied by the Malaria Technician from the respective health center, conducts this investigation. Oftentimes a report of an outbreak will reach the Health Minister.

Passive case detection (PCD) is the main method of parasitological surveillance in Bhutan. Despite the challenges of rugged terrain, health facilities with microscopy testing are available at the national, regional, and district levels. BHUs at the community level provide the bulk of malaria diagnosis using microscopy, using RDTs in the rare instances where microscopy is not available [11]. The Global Fund supported the introduction of these bivalent (*P. falciparum* and *P. vivax*) RDTs in 2006, and since that time 9,744 RDTs have been delivered to Bhutan [2]. These RDTs, if all were used (and most were used in emergencies only), represent a small portion of the total malaria tests (180,156) conducted over that time period. Back-up blood smears taken from all RDT-confirmed patients are sent to the VDCP to be tested [24].The policy in Bhutan is to give treatment according to the RDT result in the case of RDT-testing, before confirmation of the blood smear. However, only the results of microscopy confirmation are reported.

The number of blood films collected in health facilities has declined over the past 10 years by 28.0%, with 55,046 films collected in 2010. In 2010 the ABER was 20.9%. This decline is in accord with the decline in malaria cases. Blood films collected from non-nationals varied over the last 10 years, and in 2010 there were 7,624 blood films collected from non-nationals.

Proactive case detection (ACD), or household malaria screening of those with fever by surveillance workers, was conducted in Bhutan in the 1960s and 1970s, but has not been employed since that time. The elimination strategy, beginning in 2010, calls for the reintroduction of monthly proactive ACD, or focal screening and treatment by mobile clinics, with the aim to eliminate parasite reservoirs. These clinics would be implemented by the BHUs, carried out by village health workers or volunteers, as they are located in the risk areas. Malaria screening does not occur in antenatal clinics.

4.4.5 Malaria control strategies and interventions

Prevention and vector control. The major prevention and vector control interventions in Bhutan are IRS, ITNs, and LLINs. Larviciding and environmental management have been explored only through small-scale projects. Up until 1998, IRS was the main method of vector control, applied in malaria-endemic southern districts every 6 months with a goal of universal coverage. IRS is not conducted in other areas besides these southern districts. From 1998 to 2004, however, IRS was halted as ITN distribution became the main control tool. In 2004, IRS was re-introduced using new stratification criteria. Targeted spraying was employed according to these criteria, which were areas with confirmed malaria cases, *P. falciparum* rate above 5%, Slide Positivity Rate (SPR) above 3%, Annual Parasite Index (API) above five cases per 1,000 population, and presence of malaria deaths within the past 3 years. No IRS was used in the areas at risk for seasonal transmission in the interior. In 2006, LLINs were introduced alongside the continuation of focal IRS. From 2011 onwards, taking into account major reductions in caseload, the stratification thresholds for deployment of IRS became more stringent, to an SPR above 2% and an API above 4 per 1,000 population. Vector prevalence, vector behavior, and proximity to populations along and across the border were introduced as additional stratification criteria for use of IRS. Focal IRS is carried out in villages that do not meet the IRS stratification criteria. Focal IRS consists of spraying households within a one-kilometer radius of an indigenous case when reported. A Malaria Indicator Survey (MIS), which contained a Knowledge, Attitudes and Practices (KAP) component, was conducted in 2009 and found that 57% of respondents in the survey felt that “IRS did help in controlling the number of mosquitoes” but that many believed that “IRS effects were short-lived” [27]. 87% of households preferred using a bed net to IRS.

VDCP records indicate that population coverage of IRS, measured by the number of households sprayed out of the number of households targeted specifically for IRS, was on average 97.8% over the period 2004 to 2009. The WHO programme review similarly reports IRS coverage as “over 90%” [12]. However, population coverage estimated by the number of persons covered by IRS out of the estimated population at risk by district indicates a lower level of coverage. An average of 36.1% of the population at risk received IRS from 2004 to 2009. In 2009 coverage per person at risk peaked at 50.9%.

The Government of India has supported procurement of insecticides for the Bhutan VDCP since the 1960s. DDT (dichlorodiphenyltrichloroethane) for IRS was introduced in 1962 as part of the malaria eradication programme, and its application might have eliminated the primary vector, *An. minimus* [28]. DDT use was halted in 1995 with growing evidence of resistance in

Anopheles maculatus. As a result, deltamethrin, a synthetic pyrethroid, was introduced for IRS and for the impregnation of mosquito nets [28]. In 2008, cyfluthrin was introduced for IRS because the VDCP could not procure adequate supplies of deltamethrin.

ITN distribution began in 1998 [29]. By the end of 2008, an estimated 90% coverage was reached in endemic areas, with two rounds annually of treatment in endemic areas and one round in epidemic areas [19]. In 2006, LLIN distribution began, with support from the Global Fund. LLINs were sent to the health centers which in turn distributed to households. While the majority of LLINs were sent to the endemic southern districts, more than 20,000 LLINs were sent to areas throughout the country considered “hard-to-reach,” or more than 3 h walking distance from the nearest health center or BHU.

A total of 228,053 LLIN were distributed from 2006 to 2010. In 2010, coverage of households specifically targeted for LLIN was 96.9%, and a household survey in 2009 found that 82.5% had at least one LLIN [27]. However, when calculating 2010 coverage as the number of people protected out of the total population at risk, 77.2% of the risk population in the endemic, southern districts were protected by LLINs (assuming LLINs were appropriately used, provided protection for two people, and were effective for at least 3 years). Appropriate utilization rates of both ITNs and LLINs are estimated to be 90.1% [27].

Entomological surveillance is implemented in the endemic, southern districts and this includes vector population monitoring. Vector density studies, bio-assay tests on LLINs and susceptibility tests are conducted on a monthly basis. Insecticide resistance monitoring is conducted through three sentinel sites in Sarpang District, the border district with the highest number of cases. The elimination programme calls for the expansion of insecticide resistance studies to the areas in the interior at risk for seasonal transmission.

Treatment and prophylaxis. *Plasmodium vivax* infections in adults were treated with chloroquine up until 2005, when the treatment policy changed to use of primaquine (0.25 mg/kg) for 14 days and chloroquine (25 mg/kg for adults) in divided dose over 3 days. This primaquine dose is considered effective by the VDCP, although WHO guidelines suggest that in Southeast Asia higher doses are required [30]. A 2010 review of *P. vivax* treatment suggested that 0.375 mg/kg base weight is the minimum dosage to eliminate hypnozoites [31]. However, the dose has not been increased because of the risk posed to G6PD-deficient individuals. There is no point of care test for this blood disorder to use before treatment in Bhutan. Patients take this treatment at home, without observation, and are asked to report any signs indicating hemolysis. To date, there have been no reports of adverse events to the Drug Regulatory Authority regarding primaquine treatment. There are also no reports available on concerns by health workers or patients relating to use of primaquine. Treatment for uncomplicated *P. falciparum* infections from 2000 onward consisted of artesunate (3 days) with doxycycline (7 days) for adults. Artemisinin-combination therapy (ACT) was introduced in 2006 (artemether-lumefantrine). From July 2011 revised guidelines include the administration of a single dose of primaquine (0.75 mg/kg) as an anti-gametocyte for *P. falciparum* infection, without prior G6PD testing. Adult patients with mixed parasite infections receive artemether-lumefantrine (24 tablets) with primaquine (15 mg) daily for 14 days for radical cure of *P. vivax*. Malaria chemoprophylaxis is not recommended in Bhutan.

Severe and complicated *P. falciparum* infections receive artemether (3.7 mg/kg) intramuscular injection upon admission, then injections (1.6 mg/kg) once a day followed by a full course of artemisinin-combination treatment (ACT) with artemether-lumefantrine (AL) when able to tolerate oral medicines. Alternatively, intravenous administration of quinine followed by oral doses is given.

Three-day compulsory admittance to hospital is applied to all *P. falciparum* infections and patients receive directly observed therapy, with a blood slide conducted each day. Patients are then advised during discharge to return for a repeat blood slide examination after 3 days. If the patient does not return the Malaria Technician retrieves a blood slide from this person at least once. Post-treatment follow-up of *P. falciparum* cases started with Global Fund Round 4 support, but was already in practice in health centers in some endemic districts. Case follow-up of *P. falciparum* cases is now mandatory, including case investigation with monitoring of vector breeding sites conducted by BHU staff. A report form is used for this investigation, capturing information on patient travel history, reported adherence to treatment, household residents, LLIN condition, IRS coverage, and potential breeding sites. Twenty-eight day follow-up of *P. vivax* infections to measure treatment adherence and efficacy is planned but not yet introduced.

Since 1984 drug efficacy monitoring for the most part has focused on treatment of *P. falciparum*. In 2006, five sentinel sites were established in endemic districts to monitor drug resistance to ACT, and the efforts were further boosted by Global Fund support (Round 7). The ACT AL has been shown to be 100% efficacious for the treatment of *P. falciparum*, according to the VDCP. The elimination strategic plan calls for therapeutic efficacy studies of *P. vivax* treatment.

4.4.6 Enabling and challenging conditions in malaria control and elimination

In addition to the national programme strategies and interventions developed and implemented to control and eliminate malaria, there are also environmental and socio-economic factors that can directly impact malaria transmission. These factors are considered below.

Enabling conditions. Bhutan has made major advances in economic development in the last decade. Gross National Income (GNI) per capita nearly tripled from 2000 and 2009, from $730 to $2,030 (current USD, Atlas Method)—the latter figure being the highest GNI per capita in South Asia [21]. Road length increased by 43% from 2001 (3,746 km) to 2008 (5,363 km). Tourism revenue more than quadrupled during the same period ($9.2 million USD to 38.8 million).

In addition to economic advances, Bhutan has strengthened its health system and offers free health services for all. The WHO awarded the country its 50th anniversary award for primary health care in 1998, referring to its system as "one of the best in South–East Asia" [32]. The country's elimination agenda benefits from a stronger health system than exists in most lower-middle income countries. Bhutan is currently one of the leading countries in per capita expenditure on health, on par with Sri Lanka, spending up to $75 per capita (current USD) [21].

From 2000 to 2009, there was a 61% increase (109–176) in the number of physicians in the national health system [33]. There was also an increase in births attended by trained personnel, from 24% in 2005 to 66.3% in 2008 [34]. The malaria programme also benefits from a strong national supply and logistics system: for example, there were no reported anti-malarial drug stock-outs in recent years [12]. District and sub-district health facilities coordinate movement of supplies to avoid stock-outs.

Bhutan's health services are nearly all provided by the public sector. There are no private medical facilities and only a handful of retail pharmacy shops [12,35]. As a result, the government has a high level of control of case management and malaria control measures.

Challenging factors. First, rugged terrain and remote, hard-to-access population groups create challenges in access to healthcare facilities. The majority of the population (69.1%) live in rural areas [5]. As stated above, 21% of the population is considered "difficult to access" in that they are located more than 4 h walk from the nearest road. Access is further impeded by rain, landslides and road closures during the major monsoon season, which is also the peak season of malaria transmission. Delays in treatment have been associated with remoteness and the cost of transportation to health facilities [35]. In addition, there is a strong tradition of traditional medicine in Bhutan whose practice can delay prompt and correct malaria treatment [35].

Although over the last decade there have been recent improvements in the number of staff available in the national health system, historically there have been shortages of highly trained workers are a result of the limited training institutions located in Bhutan. There is no medical college and physicians and most technical professions are trained abroad [8,21].

While the socio-economic development taking place in Bhutan may play a role in reducing the receptivity to malaria transmission, there are major development projects underway that could undermine those advances. Major construction of hydropower dams and other projects may expand vector-breeding habitats and have led to large influxes of migrant workers, typically from malaria endemic regions of India and Bangladesh, thereby increasing the risk of importation of malaria and onward transmission. There are an estimated 35,000 documented migrant workers in Bhutan, the majority of which are employed in large-scale development projects in the interior and southern districts. While a recent cross sectional survey conducted in two hydroelectric plant construction sites indicated a low level of parasitaemia in worker groups, the overall risk posed by these migrants is not known [36]. The majority of workers surveyed were from the Indian states of West Bengal, Bihar, Jharkhand, and Uttar Pradesh [36]. Outside of migrant labor, further population movement results from the national resettlement programme, which relocates Bhutanese from low transmission areas to endemic areas to increase access to arable land. These resettled populations may both lack malaria immunity and knowledge about the disease and its prevention and treatment [35].

Thirdly, there have been recent short and long-term changes in climate and rainfall, which are thought to have contributed to the increase in incidence in 2009 [12]. Climate-related severe weather patterns have been observed, and increasing temperatures and changes in rainfall are predicted to have major health impacts [37].

Lastly, and perhaps the greatest threat to a successful elimination plan, is the border with Assam State of India. The porous border is malaria-endemic, largely composed of forest reserve, and is characterized by historical political instability, transient and semi-permanent settlements, mobile populations, and impoverished conditions. There are virtually no malaria surveillance or referral services, apart from non-governmental organizations (NGOs) based in the area [23]. As a result, Assam population groups often migrate into Bhutan seeking healthcare services, in particular at Sarpang District Hospital. Other migrant groups include daily contractual workers and casual laborers. There is an estimated daily migration of 1,000 people entering Bhutan through each regulated checkpoint in ten border towns. It is unknown how many migrants pass through unregulated areas of the border, and as these populations have not been studied, there are no certain estimates of cross border movement. A clearer understanding of the migration pathways into and within Bhutan would help in targeting interventions to prevent importation of malaria.

4.4.7 Elimination strategy

The decision to pursue malaria elimination in Bhutan, which aims to eliminate first in the interior of the country and progressively work toward the southern border areas, was shaped by sustained low malaria incidence in the interior of the country over the last 10 years. In most of this area there have been no indigenous cases of malaria in 3 years, with few imported from the border districts. In addition, the epidemiological, technical and programmatic assessment of the malaria programme review, conducted in March 2010 in collaboration with WHO, supported the decision to pursue elimination [12]. Progress made in the South–East Asia region, such as recent successes in Sri Lanka and Thailand, also influenced the decision to eliminate [38].

Progressive malaria elimination in Bhutan will require intensified efforts in case-based surveillance, with rapid notification, case investigation and case containment strategies. The expansion of parasitological and entomological surveillance is a priority, and must include the identification and mapping of local malaria foci, which is dependent upon the creation of district-level case investigation and rapid response teams. The expansion of outreach clinics, typically used for vaccination and antenatal activities, to include malaria PCD and methods of ACD will enhance surveillance in remote areas. Case management policies will also be strengthened—case follow-up for one month for *P. falciparum* infections is planned, and a 14-day follow-up period for *P. vivax*. Case-based IRS, when indigenous cases are found, is planned to be implemented in the interior districts, where IRS has not yet been employed.

A cross-border malaria strategy with India has been identified as a necessary next step in order to achieve elimination in Bhutan. Over the years, several efforts were made to establish cross-border mechanisms for Bhutan and India to improve malaria control, surveillance, information sharing and research along the border zone. In the early years of the malaria programme, in the 1960s, IRS activities were synchronized along the border. In the mid-1990s, WHO supported meetings between the countries seeking to improve information-sharing through study tours, conduct joint training and strengthen entomological surveillance. However, these activities were not sustained.

In 2000, the USAID Bureau for Asia and the Near East (ANE) and USAID Nepal, in collaboration with WHO, supported a regional initiative of Bangladesh, Bhutan, India, and Nepal (BBIN) to implement cross-border activities for control of malaria, leishmaniasis, and Japanese encephalitis. The goal was to support the development of new interventions, expansion of proven interventions, and to improve surveillance programmes. Guidelines for surveillance, research studies, an IEC national programme, and a surveillance system were developed for Bhutan. The BBIN project was eventually disbanded due to a reduction in funding.

The current elimination strategy focuses mainly on management of imported malaria. Six border malaria screening centers will be installed at security checkpoints in five districts. The planned border malaria screening and LLIN distribution will target both at-risk Bhutanese and migrant workers in construction sites.

4.5 Discussion

Bhutan has achieved a 98.7% decrease in microscopy-confirmed malaria cases from 1994 to 2010. Declines occurred in the zone at risk for seasonal transmission in the interior of the country as well as in the endemic, southern border districts [24]. In 2004, Bhutan met and surpassed the Millennium Development Goals set by RBM, achieving over 50% reduction in cases well ahead of the 2010 goal. Stemming from this success, and building on the strengths of the national health system and the Vector-borne Disease Control Programme, Bhutan is embarking on malaria elimination.

The evidence-based strategies implemented by the VDCP are likely the root of Bhutan’s malaria success, along with the economic and social development seen in the country. The programme benefits from a strong primary health care system and continually expanding access to health care, including malaria diagnosis and treatment, at the district and sub-district levels in rural and remote areas. A well-functioning health supply system allows few stock-outs. As a result of these improvements, access to timely diagnosis and treatment through PCD has likely improved, with weekly case reporting linking epidemiological trends to vector control measures. Evidence-based case management policies, including the implementation of ACT for *P. falciparum* cases, may have also contributed to the declining transmission [24].

The deployment of IRS, ITN, and LLIN with the use of strong stratification criteria has resulted in high coverage of targeted populations most at-risk, contributing to the downward trend in incidence [6,24]. Global Fund grant support increased access to these prevention measures.

In order to maintain the progress of the last decade, Bhutan must address the challenges it faces to eliminate malaria. The increase in cases that occurred from 2008 to 2009 is an indicator that there is still more work to be done. Further studies on understanding mosquito vectors and their bionomics are warranted in order to formulate more specific intervention strategies. The Malaria Technicians deployed by the VDCP are a pillar of the programme and must be maintained in order to ensure vigilance and timely response. The integration of duties of Malaria Technicians could potentially lead to a weakened response to malaria outbreaks and this must be avoided. Increases in transmission across the southern border in Assam or West Bengal, India may directly impact transmission in southern Bhutan [24]. Adding to the risk is the continual migration into Bhutan from these states, regulated and unregulated and daily and long-term, which may continually reintroduce infections into all receptive areas of the country [7]. A clear understanding of the origin and pathways of migrants into Bhutan would facilitate the development of effective strategies to mitigate and manage imported malaria and the risk of onward transmission.

4.5.1 Limitations

This case study is based on a retrospective analysis of national surveillance data on confirmed malaria infections. The number of unconfirmed cases is not known, yet the relatively high level of access to public health facilities and lack of private sector facilities translates to a negligible level of unconfirmed infections. The epidemiology data does not allow for a more extensive analysis of the malaria infection of long-term migrant workers in Bhutan. National case investigation procedures have not collected enough information to identify the origin of infection, but will attempt to do so in the future.

4.6 Conclusions

Bhutan has made great strides towards elimination. The greatest challenge to this goal is in identifying and containing imported infections from the neighbouring Indian states. The malaria programme has identified two main approaches to face this problem. Firstly, implement border screening and secondly, develop cross-border and regional malaria collaborations [7]. A recent WHO report recommends border post screening for malaria not only to identify and treat infections, but also to install a way to measure increases in transmission in order to adequately prepare response measures [36]. Overall, though, evidence is lacking on the impact of border screening, with only a few available examples, most from island contexts which are obviously very different than landlocked Bhutan. The Thailand-Cambodia artemisinin resistance containment project has included mobile malaria clinics at border crossings in Thailand, but this activity has not been assessed for impact on transmission reduction [39]. Recent research on a passenger screening surveillance programme in Mauritius [40] and the acceptability of inter-province port screening in Solomon Islands [41] provides some examples of identification of imported malaria infections, but more research is needed. In Bhutan, where borders are porous and migrant populations pass daily over the border, other measures may be needed in addition to the border screening centers, which target longer-term migrant workers. Regional or cross-border initiatives may be an important tool to lower importation risk [1,7]. Harmonized surveillance, case management and vector control strategies and their synchronized implementation in border regions are generally successful through a multi-country platform. Yet the history of cross-border collaboration between Bhutan and India attests to the challenge of developing such an initiative, from getting the key partners to the table to finding sustainable funding support. The cancellation of Rounds 11 and 12 by the Global Fund speaks to the latter challenge. As more countries near elimination, regional approaches, backed by sound evidence and supported with adequate funding, are likely to be the way forward.

4.7 Acknowledgements

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CHAPTER 5

Strategies and approaches to vector control in nine malaria-eliminating countries: a cross-case study analysis

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5.1 Abstract

Background: There has been progress towards malaria elimination in the last decade. In response, WHO launched the Global Technical Strategy (GTS), in which vector surveillance and control play important roles. Country experiences in the Eliminating Malaria Case Study Series were reviewed to identify success factors on the road to elimination using a cross-case study analytic approach. Methods**:** Reports were included in the analysis if final English language draft reports or publications were available at the time of analysis (Bhutan, Cape Verde, Malaysia, Mauritius, Namibia, Philippines, Sri Lanka, Turkey, Turkmenistan). A conceptual framework for vector control in malaria elimination was developed, reviewed, formatted as a matrix (in Excel), and populated with case study data. A workshop was convened during which participants reviewed the case studies, matrix summaries and findings and arrived at a consensus on the evidence and lessons. Results: Countries implemented a range of vector control interventions. Most countries aligned with integrated vector management, however its impact was not well articulated. All programmes conducted entomological surveillance, but the response (i.e., stratification and targeting of interventions, outbreak forecasting and strategy) was limited or not described. Indoor residual spraying (IRS) was commonly used by countries. There were several examples of severe reductions or halting of IRS coverage and subsequent resurgence of malaria. Funding and operational constraints and poor implementation had roles. Bed nets were commonly used by most programmes; coverage and effectiveness were either not measured or not articulated. Larval control was an important intervention for several countries, preventing re-introduction, however coverage and impact on incidence were not described. Across all interventions, coverage indicators were incomparable, and the rationale for which tools were used and which were not used appeared to be a function of the availability of funding,

operational issues and cost instead of evidence of effectiveness to reduce incidence. Conclusions: More work is required to fill gaps in programme guidance, clarify the best methods for choosing and targeting vector control interventions, and support to measure cost, cost-effectiveness and cost-benefit of vector surveillance and control interventions.

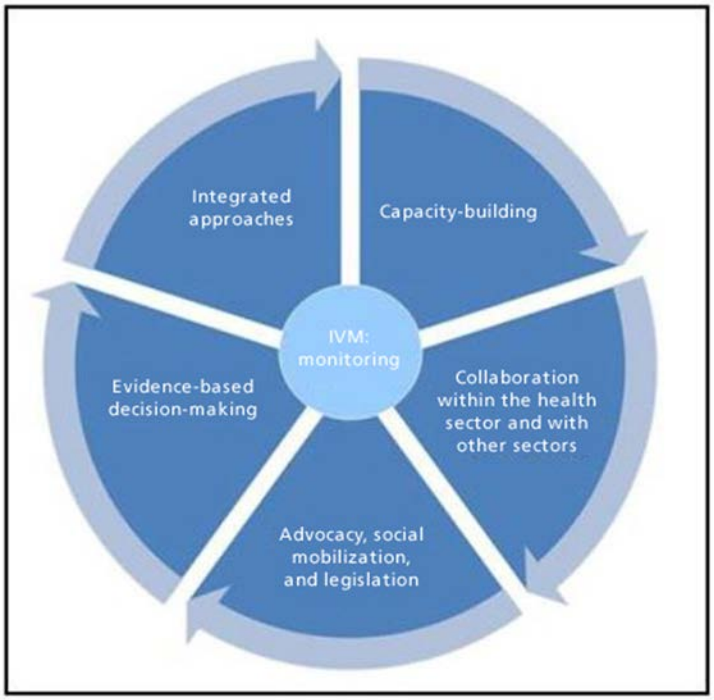
5.2 Background

Tremendous progress has been made over the last decade in reducing morbidity and mortality from malaria. At present, 55 countries are on track for or have already achieved a 75% reduction in morbidity from 2000 to 2015 [1]. This progress has prompted a review of the current global malaria strategy and goals, set forth in the *Global Technical Strategy for Malaria 2016-2030* (GTS) by the Global Malaria Programme of the World Health Organization (WHO) and its implementation and action framework, *Action and Investment to Defeat Malaria* (AIM) by Roll Back Malaria (RBM). GTS was approved by the World Health Assembly in May 2015 and AIM by the RBM Advisory Board in the same month [2,3]. Out of the three pillars laid out in the GTS to ensure continued progress towards and achievement of malaria elimination, two emphasize the role of entomological surveillance and vector control response.

Vector control encompasses the measures that are directed against a vector of disease, intended to limit its ability to transmit the disease by protecting areas that are known to be receptive to transmission [4]. Receptivity to malaria depends on the vectorial capacity of local vector populations, as in not just the presence of the vector but its population size, human biting habits and longevity in relation to the period of sporogony. Each of these parameters is strongly influenced by the climate, local ecology and behavior of both humans and vectors. . In an elimination phase, the objective of vector control is the reduction of the vectorial capacity of the local vector populations below the critical threshold needed to maintain transmission [5].

The GTS outlines the need for high-quality implementation of core vector control tools of indoor residual spraying (IRS) and long-lasting insecticide-treated bed nets (LLINs), as well as the role of larval source management as a supplementary tool. Integrated vector management (IVM) should be the overarching vector control strategy for all countries, and includes the components described in Figure 5.1 [6, 7].

Figure 5.1: IVM framework and distinguishing characteristics. Source: Beier JC, Keating J, Githure JI, Macdonald MB, Impoinvil DE, Novak RJ. Review: Integrated vector management for malaria control. Mal Journal. 2008;**7:**S4.



Routine entomological surveillance (e.g., vector mapping and bionomics) and insecticide resistance monitoring data should be combined with epidemiological data to identify new vectors or shifts in vector composition, understand receptivity in a country setting, inform choice of vector control interventions, coverage, timing, and to evaluate the quality and impact of interventions. When malaria burden is reduced to low levels, a shift from universal to targeted vector control activities is needed for those programmes that are ready for this transition. Plans must be in place for the management of insecticide resistance, operational research to develop and validate new tools, as well as strategies to improve upon microstratification and delivery of interventions.

As vector control is an important component in the overall strategy to control and ultimately eliminate malaria, there may be factors in its implementation that influence the likelihood of attaining malaria elimination. Vector control intervention choice and how it matches the context of vector habitat and behaviours, targeting and coverage of at-risk populations, and evaluation and modification of programme interventions may influence the success or failure of malaria elimination programmes. The Eliminating Malaria Case Study Series by the WHO Global Malaria Programme and University of California, San Francisco (UCSF) Global Health Group provides detailed examples of national malaria programmes that are currently eliminating or have eliminated malaria, offering an opportunity to review synthetically key components of these programmes. In this paper a review of vector control activities across nine countries was undertaken to identify success factors along the road to elimination using a cross-case study, analytic approach. The analysis focuses on vector control tools, approaches, coverage and, when information was available, impact in elimination settings.

5.3 Methods

This cross-case study review included nine case studies from the Eliminating Malaria Case Study Series, produced through a collaboration between the WHO Global Malaria Programme and UCSF Global Health Group. Each case study details the program strategies and interventions from the early 1900s to the current period, with epidemiological and intervention data coverage and an analysis of the main factors behind their successful handling of outbreaks or epidemics and programmatic challenges. Countries were selected for the case study series if they: a) demonstrated successful transition towards or achievement of elimination; b) committed to the case study research and analysis process; and, c) were able to provide access to sufficient data. Countries were also chosen to represent a range in malaria epidemiology, stage of elimination (from low endemic control to prevention of re-introduction), geography (island vs continental), and strength of their health system. Countries selected were Bhutan, Cape Verde, Malaysia, Mauritius, Namibia, Philippines, La Reunion, Sri Lanka, Tunisia, Turkey, and Turkmenistan [8-16]. Table 5.1 shows the different stages and goals of the nine countries that were included in this review. Prevention of re-introduction (POR) countries were those considered to have reached zero locally acquired cases and are actively preventing re-introduction of malaria [4].

Table 5.1: Elimination history and goals of the nine case study countries

COUNTRY	**BTN**	**CPV**	**MYS**	**MUS**	**NAM**	**PHL**	**LKA**	**TUR**	**TKM**
ELIM-INATION STATUS	Elim-inating	Elim-inating	Elim-inating	Prevention of Reintro-duction	Elim-inating	Elim-inating	Elim-inating	Preven-tion of Reintro-duction	Prevention of Reintro-duction
ELIM-INATION HIST-ORY	Goal of zero transmission nationally by 2018; national malaria elimination certification by 2020.	Achieved zero cases 1968-72 but epidemic occurred during 1977-79. Second elimination attempt 1983-85, however epidemic occurred during 1987-88. Goal of national elimination by 2020.	Goal of national elimination by 2020: elimination in West Malaysia by 2015 and elimination in Sabah and Sarawak by 2020.	First eliminated in 1969 and received WHO certification in 1973. Resurgence in 1975. Second elimination achieved by 1998.	Goal of national elimination by 2020.	Strategy of progressive sub-national elimination with national elimination (all provinces) by 2025 (recently updated to 2030).	Near elimination in 1963, then an epidemic from 1967-68. Zero local cases reported since November 2012; will seek WHO certification by end of 2015.	Most of the country in consolidation phase in 1974, followed by epidemics in 1977 and 1993-1996. Last indigenous cases reported in 2012 during outbreak.	First eliminated in 1961. In most recent attempt, the last indigenous case occurred in 2004. Received WHO certification in 2010.

BTN: Bhutan; CPV: Cabo Verde; MYS: Malaysia; MUS: Mauritius; NAM: Namibia; PHL: Philippines; LKA: Sri Lanka; TUR: Turkey; TKM: Turkmenistan

Case studies were included in the cross-case analysis if they were part of the WHO Global Malaria Programme/UCSF Global Health Group case study report series, all of which used the same type of quantitative and qualitative approaches and methods. Reports or publications that were in final English language draft at the time of analysis (November 2014) were included. Case studies included in this cross-case analysis are Bhutan, Cape Verde, Malaysia, Mauritius, Namibia, Philippines, Sri Lanka, Turkey, and Turkmenistan. Case studies from La Reunion and Tunisia were not included in the cross-case study review because the report from La Reunion was not finalized nor translated into English at the time of analysis, and a draft of Tunisia was not yet available by the time the analysis was underway.

A conceptual framework for vector control in malaria elimination was developed to provide structure for the cross-case analysis. To develop this framework, a document review was conducted of malaria elimination vector control guidelines, reports, consultations, and manuals to identify historical and current policy and research on vector control strategies, entomological surveillance, operational research, and costs. Search terms included 'vector control' and 'malaria elimination' or 'malaria'; or 'indoor residual spraying', 'insecticide-treated nets', 'long-lasting insecticide treated nets', 'entomology', 'entomological surveillance', 'larval control', and 'larval source management' in the following search engines and databases: The Cochrane Library, PubMed, Google Scholar, and WHOSIS. Using this literature, a conceptual framework of vector control strategies and interventions was developed based on the topic areas of vector species and behaviour, approach to vector control, tools and coverage, combination interventions, stratification, outbreak response, implementing organizations, and cost of activities. The framework was reviewed by malaria elimination and vector control experts and formatted in Excel as a matrix. A first round of data extraction from the case study reports occurred as a result of a thorough review of the nine reports by two researchers (CSG, GN). CSG and GN then extracted challenges and weaknesses of the vector control programme for each case study and reviewed each other's summaries. This analysis focused on the vector control strategies and tools used after the Global Malaria Eradication Programme (GMEP, 1955-1970), in order to reflect current tools (e.g., LLINs) and research.

Once the matrices with data and summaries were assembled, a two-day workshop of malaria elimination researchers and experts was convened to review the case studies, matrix summaries and findings to ensure that the data captured in the matrix were comprehensive and to debate the different learning across the country experiences. Workshop participants revisited the principles of vector control (aims, objectives, what implemented, how implemented, by whom) and identified examples from each case study report for each of the elements of the framework, arriving at a consensus on the evidence and lessons learned from the case study series. A second round of data extraction and summary was undertaken to ensure that data was extracted for each portion of the framework. The results of the cross-case analysis were then compared with the strategies laid out in the GTS.

5.4 Results

The review of case studies showed that all countries implemented a range of vector control interventions, whether they had eliminated (Mauritius, Turkey, Turkmenistan) or were moving towards elimination (Bhutan, Cape Verde, Malaysia, Namibia, Philippines, Sri Lanka). The types of intervention used were likely determined by many factors, including operational constraints, cost, vector density and behaviour, insecticide resistance levels and epidemiological trends, among others. The vector control tools used by each country can be found in Table 5.2.

Table 5.2: Vector control intervention mix across the nine case study countries

	GTS tool	**BTN**	**CPV**	**MYS**	**MUS**	**NAM**	**PHL**	**LKA**	**TUR**	**TKM**
Primary vectors		*An pseudowillmori* *An culicifacies*	*An. Arabiensis (An gambiae complex)*	West Malaysia: *An. Maculatus* Sabah: *An. balabacensis* *Sarawak: An. latens, An. donaldi*	*An. gambiae s.l.* (identified as *An. arabiensis* in 1975)	*An. arabiensis*	*An. flavirostris* *An. maculatus*	*An. culicifacies (species E)*	*An. sacharovi* *An. superpictus*	*An.pulcherrimus* *An. superpictus*
IVM	X	2		2				2		2
Entomo-logical surveillance	X	2	2	1	1 C	2	2	1	2	1
Response to Entomo-logical surveillance	X			2	2		2			
IRS	X	1	2	2	2	1	2	1	2	2
Thermal fogging					2			2	2	
LLIN/ITN	X	1		2[a]		1	2	1	2	2[b]
Larvivorous fish	X		2				2	2	1	C
Larviciding	X	2	2	2	1	2	2	2	1	
Environ-mental manage-ment			2	2	2		2	2	2	2
Personal protection							2			2

Notes:

BTN: Bhutan; CPV: Cabo Verde; MYS: Malaysia; MUS: Mauritius; NAM: Namibia; PHL: Philippines; LKA: Sri Lanka; TUR: Turkey; TKM: Turkmenistan

GTS: Global Technical Strategy

1 Primary vector control intervention during most recent elimination strategy.

2 A vector control intervention implemented during recent elimination program, but not considered primary.

C Strategy used during Consolidation phase (after having achieved elimination).
a ITN only
b Locally produced bed nets

The IVM strategy document was disseminated by WHO in 2004 [17]. Most countries that were eliminating or had eliminated had strategies in place that used components of IVM, in particular the combination of interventions. IRS, insecticide-treated nets (ITNs) and LLINs were used commonly by most programmes to collectively increase population coverage, along with larval control. Some countries supplemented these interventions with environmental management, personal protection and insecticide fogging. Implementation most typically occurred at the district level, with guidance and strategy development provided at the national level. Some reports showed outsourcing of vector control activities to community volunteers or the private sector. There was little explicit description of the other four components of IVM, such as collaboration in health and with other sectors; advocacy, social mobilization and legislation; capacity building; nor development and use of evidence-based decision making.

The rationale for which tools were used and which were not used was not well-articulated in the case studies. Moreover, there did not appear to be a clear linkage between entomological surveillance data, including insecticide resistance data, and parasitological data, nor was there evidence that either types of data informed intervention choice. Instead, the availability of funding and cost of interventions appeared to have played an important role in decision making for vector control interventions. The coverage and targeting of interventions was also poorly reported in the case studies. Some case studies included detailed stratification strategies, but not all. Even for those with a stratification strategy, most case studies did not consistently report on intervention coverage, and the ways in which coverage was described varied enormously, making comparisons across time periods and countries difficult. There was little evidence of reported quality assessment of interventions.

Measurement or evidence of impact of vector control interventions was scant or practically absent. Many case studies indicated that activities were effective in reducing receptivity in risk areas, but did not provide evidence or indicators, instead using anecdotal evidence that was likely based on programme experience.

In the analysis, the targeting, coverage and impact of all vector control measures were compared across the case study countries and similarities and differences highlighted. The results are described below for each vector control approach and tool.

5.4.1 Integrated vector management

IVM was adopted by four of nine programmes in the cross-case study analysis, but the meaning and utility of IVM varied across case studies (Table 5.3). The strategy of IVM was introduced in 2004 by WHO to increase cost effectiveness of vector control and to reduce the spread of drug and insecticide resistance [17]. The strategy focused on using a combination of interventions to attack the vector at different stages of its life cycle. It also requires decisions on which tools to use to be made based on evidence and that the type of vector control deployed will change as one approaches elimination and post-elimination (Figure 5.1). For some countries (e.g., Turkmenistan) it was used as a way to combine vector control interventions. In other countries it ensured intersectoral collaboration, community engagement and integration of services, such as entomological surveillance, with other diseases (e.g., dengue). In Sri Lanka, IVM combined all of these elements, and engaged other sectors and communities in developing vector control strategies. It also ensured the use of a mix of interventions, as well as insecticide rotation for IRS, in which different types of insecticides were used in bordering districts with rotation of insecticides across districts over time, in order to lessen the risk of the development of insecticide resistance.

Table 5.3: Integrated Vector Management (IVM) adoption and definition

	BTN	CPV	MYS	MUS	NAM	PHL	LKA	TUR	TKM
Implementation of IVM and timeline	X (National Five-Year Plan 2008-2013)		X (2011)				X (Mid 1990s)		X (1998)
Components of IVM implemented:									
-Intersectoral collaboration			X				X		
-Community engagement	X						X		
-Insecticide rotation							X		
-Combination of vector control interventions	X						X		X

BTN: Bhutan; CPV: Cabo Verde; MYS: Malaysia; MUS: Mauritius; NAM: Namibia; PHL: Philippines; LKA: Sri Lanka; TUR: Turkey; TKM: Turkmenistan

The impact of IVM was not articulated in the reports, except for Sri Lanka, where the use of the approach in agricultural areas was thought to have contributed to a reduction in malaria incidence. Further research would be valuable to understand the impact of implementation of IVM as a broad strategy on reducing malaria transmission.

5.4.2 Entomological surveillance

Most countries in the case study series began conducting entomological surveillance during the GMEP. Entomological surveillance is typically comprised of monitoring of larval habitats, surveying for adult mosquitoes, conducting insecticide susceptibility tests, and assessing changes in environmental parameters [4], with the objectives of identifying the level of change in receptivity, and of designing and monitoring effectiveness of programme vector control strategy and interventions. The case studies did not outline specific activities that were maintained in the current elimination periods, instead only providing details and time frame when a new effort or initiative was undertaken. Even for countries that had more consistent entomological surveillance, the response component was not articulated in the case studies; it appears that, for most countries, entomological surveillance data were not analysed and used for outbreak forecasting or programme strategy, including better targeting of vector control interventions.

There was variation in the quality and consistency of entomological surveillance across the case studies. Countries that have reached elimination generally had a more detailed description of their surveillance programmes. For example, in the years leading up to elimination in Turkmenistan (2004-10), the programme maintained ‘passports’ for each water body, and district officials systematically updated a database on vector bionomics and densities. Entomological officers were recruited to serve on epidemic response mobile teams. In Turkey, surveillance included mapping of larval habitats in addition to data collection in sentinel sites. The continuation of this type of surveillance through the years of POR and post-elimination certification was only described in detail in the Mauritius report, where the programme maintained weekly surveillance of breeding areas since elimination in 2008.

The Malaysia and Sri Lanka case studies likewise described strong entomological surveillance programmes. In both countries, consistent entomological surveillance was one of several approaches credited by the malaria programmes for the national progress in reducing incidence, as it was used to guide planning of vector control. Malaysia’s diversity of vectors was a reason for continual monitoring, and district-level surveillance tracked larval habitats (conducted by district entomologists and assistant environmental health officers). Mapping with GPS units captured housing locations and larval habitats. Sri Lanka’s national and district health offices conducted entomological surveillance on a monthly basis. In later years, Sri Lanka had a large increase in funding to support entomological surveillance (from a Global Fund grant), which was conducted by a private sector organization in some areas. In Bhutan, surveillance was conducted monthly.

In other countries, entomological surveillance was more limited, such as in Cape Verde, where there was not a consistent programme of monitoring. Surveillance in the Philippines was limited to semi-annual or annual monitoring in the sporadic and malaria-prone transmission provinces.

In all case study countries, data collected during surveillance were not consistently used by programmes. Most case studies did not describe the use of entomological surveillance data to assess impact of interventions or to inform programme strategy. For example, because Turkey did not conduct entomological evaluations pre- and post-epidemic (after 1993), the programme was unable to assess effectiveness of the response interventions. There are some examples of programmes using their entomological data to guide decision-making. In the Philippines, surveillance data were reviewed during sub-national, provincial elimination certification, a process that was formalized in 2011. In addition, prior to the national programme’s devolution, all new strategies were tested through field research and entomological and parasitological surveys before becoming policy, such as the shift from IRS alone to combined IRS with ITNs. Bioassay and susceptibility test results guided changes in insecticide usage. In Malaysia and Mauritius, maps of larval habitats were used to target vector control interventions. Also in Malaysia, research was undertaken by district and state officers to measure effectiveness of management of the larval stage of the vector in reducing receptivity, although the outcomes of this research were not described in the report.

As entomological surveillance data should be the basis for all response interventions and programme strategies, consistent and high-quality data are needed. Further action is required to ensure that entomological surveillance is a priority for elimination programmes and that data are analysed and inform robust response, including forecasting, targeting and programme strategy.

5.4.3 Indoor residual spraying

Each of the nine programmes employed IRS, and most countries continued IRS after its introduction during the GMEP era because IRS historically was found to be effective in reducing receptivity. IRS targeting strategies varied across the countries, but generally by the 1990s most countries had transitioned to focal IRS instead of universal coverage, or blanket spray, operations. This transition may have been in response to the introduction of the WHO Global Strategy for Malaria Control (1993) [18]. As all countries (both eliminating and POR) approached elimination, their programmes transitioned to targeting IRS for active foci or active transmission areas.

In the case studies there were several instances of premature reduction of coverage or disbanding of IRS, some of which were linked to subsequent resurgences of malaria (e.g., Cape Verde, Sri Lanka, Turkey). The reported reasons for reducing IRS operations varied, but the trend was that scale-down occurred when countries were very close to eliminating malaria or were firmly in the POR stage. In Sri Lanka, IRS was halted in eliminated areas, which is thought to have contributed to the epidemic of 1957. In more recent times, Sri Lanka has shown a decline in IRS coverage as it moved from full coverage of risk areas to focal IRS (conducted in areas with malaria cases) and outbreak response, moving from 23% coverage of total population in 2005 to 6% in 2010. Even without continued IRS coverage, however, to date Sri Lanka has been able to maintain low caseload and has not experienced a resurgence, perhaps related to the continued distribution of LLINs and use of larval control in addition to a strong surveillance system. In Cape Verde, in contrast, twice in recent history, foci on Santiago Island were re-activated within three years after relaxation of aggressive, bi-annual IRS operations. IRS was not replaced by another vector control intervention; larval control (temephos and larvivorous fish) was used after the 1960s in Cape Verde, but there is no evidence in the case study that it was scaled up when IRS declined, and coverage data were not available. Cape Verde has since continued its small-scale IRS operations, mainly outbreak response activities that covered about 5-10% of Santiago Island.

Turkey scaled down IRS to residual foci only when it did not achieve elimination during the GMEP, and in the 1970s and 1990s fell short of coverage of active foci that was achieved in 1961 (86-88%) and 1968 (nearly 100%). In both the 1970s and 1990s, reductions in IRS coverage were linked to the availability of funding; the malaria service was under pressure to reduce expenses when it did not reach elimination. Other challenges included operational constraints, lower quality of implementation, a high rate of refusals in the target population, and insufficient and inexperienced staff. IRS was not replaced by another method of vector control at that time, although larviciding had been used as a complementary measure since the late 1950s. In its latest strategy, the country reserved IRS for areas with residual or active transmission. Likewise, Mauritius did not have enough funding to conduct IRS island-wide during its second elimination attempt, so it was restricted to areas with ongoing transmission. Mauritius used a combination of interventions (IRS, fogging, larval control, and entomological surveillance) for areas with transmission that reported more than three cases. Areas with fewer than three cases did not receive IRS. Coverage was described as 65-80% of foci in 1986, although it was not clear in the case study if this was considered sufficient. In recent years, Mauritius used IRS to prevent establishment of transmission within a residence of a confirmed case, of which all are imported.

Some countries, particularly those in the early stages of elimination, indicated that operational constraints, instead of a stratification strategy, led to the scale-down of IRS. Worker shortages and an inability to mobilize spray teams, inadequate training, and low morale were all factors described in the case studies. In the 1990s, the Philippines reduced IRS coverage to 20% of targeted areas as a result of operational disruptions during the process of programme decentralization. Even when an increase in funding boosted coverage to two spray cycles per year with 76% of target achieved, quality was considered poor due to delays, lack of training, and an insufficient number of spraymen. In part because of the operational challenges and in part due to Global Fund influence, the country focused instead on LLIN distribution. In 2011, ITN and LLIN coverage in the 40 target provinces was 73% of the total target population. In Namibia, rainy conditions, poor roads and worker shortages have prevented completion of IRS activities. IRS national coverage of at-risk populations ranged from 16-41% from 2001-2011, and the country revised its goal to a target of 95% coverage in areas of moderate endemicity and 100% focal coverage in low-endemic regions, prioritizing the highest burden villages in the event that the spray season was cut short due to staffing or logistics problems. In Bhutan, political instability in the southern region in the early 1990s led to difficulties in completing IRS spray campaigns and by 1994 cases were increasing. IRS was halted in 1998 when the programme switched to ITNs as a primary vector control measure. Focal IRS was re-instated in 2004 and by 2012 the Bhutan programme reported achieving 100% coverage of its target population (14% of the population at risk).

Some countries appear to have maintained a consistent level of coverage. Turkmenistan employed IRS as an outbreak response measure, covering 91-100% of targeted areas during the 1998-2000 period. The programme did not conduct IRS from 2005 because there were no malaria infections to ‘trigger’ the focal IRS response. The case study on Malaysia did not report any decline in IRS activities, but it was challenging to understand the coverage because it was measured as the number of households sprayed of those targeted, and not by proportion of risk population protected.

Some programmes relied on communities or volunteers for IRS campaigns, such as in the Philippines. Bhutan also trained community volunteers to conduct IRS, however the quality and coverage declined so volunteer teams were disbanded. In some private sector plantations in

Sabah State (Borneo) of Malaysia, IRS was implemented (and paid for) by the plantations, with oversight by the Sabah Malaria Control Programme.

Effectiveness of IRS to reduce receptivity was assumed in the reports, evidenced by declines in malaria incidence in the 1950s and 1960s that were linked with increases in IRS coverage. But the picture became more complicated in recent years, as multiple interventions were employed at the same time. This was the case in Malaysia, where IRS with ITN distribution (ITN distributed began in 1995) was credited for a decrease in annual parasite index (API), the number of reported cases per 1,000 population per year, from 3.0 (1995) to 0.5 (2000), in addition to the benefits of replacing DDT with pyrethroids in 1998. Turkey and Mauritius also attributed malaria case declines to IRS activities along with active surveillance measures.

Most case study reports did not contain adequate information on recent insecticide resistance monitoring activities or description of evidence of resistance. Malaysia and the Philippines described the sentinel sites for monitoring insecticide resistance. Malaysia, Namibia, and the Philippines reported conducting bioassay and susceptibility tests on insecticides. In the Philippines, Laguna Province shifted insecticides reportedly due to a drop in effectiveness after ten years, and more recently there was pyrethroid resistance possibly detected in Isabela Province. Sri Lanka implemented insecticide rotation in 1998, part of IVM, in order to prolong the life and utility of the insecticides and optimize vector control.

Given the experience of several countries that halted or scaled down IRS and suffered serious epidemics and resurgences of malaria, further research is needed on the transmission dynamics in various types of contexts, and the alternative methods, such as larval source management, that can be put into place to avoid resurgence. Information should also be shared on the monitoring for insecticide resistance and the programmatic response to the data collected. For some countries, typically higher endemic areas, logistical issues or decreases in funding have led to poor quality implementation or disruption of IRS. Less resource intensive, sustainable methods for vector control must be explored for some countries.

5.4.4 Space spray

Outdoor space spray with insecticide was reported in the case studies of three programmes: Mauritius, Sri Lanka and Turkey.

Mauritius used space spray as an epidemic response measure starting in 1975, but by 1981 it was discontinued. Implementation was viewed as costly and ineffective because it was conducted in the morning when the temperature was too warm. The thermal clines made the insecticide rise and in addition the mosquitos were not flying at that time. It was re-instated in 1982 as a response to the outdoor-biting behaviour of *Anopheles gambiae s.l.*, this time conducted in the evening. At that time, coverage was limited to the Port Louis areas in response to outbreaks only. In Sri Lanka, space spray has been used during festivals and other large gatherings, but coverage and effectiveness was not articulated in the case study. Turkey conducted space spray as an outbreak containment strategy. While the report indicated that epidemics were controlled through a combination of interventions that included space spray, there are no data on the effectiveness of space spray alone. More research specifically on the impact on malaria transmission of space spray in countries that use it would help in developing an evidence base.

5.4.5 Long-lasting insecticidal nets/insecticide-treated nets

Most malaria programmes in the case study series employed ITNs, followed by LLINs as they became available, as a supplementary vector control measure to IRS. However, the countries in POR (Mauritius, Turkey, Turkmenistan) never used ITNs or LLINs, as they had achieved elimination before they were available. One exception is Turkmenistan, where locally made bed nets were in use since the 1930s and were reportedly widely used (coverage rates not given) in the 2004-2010 elimination campaign.

Of the six eliminating countries, Cape Verde never employed LLINs or ITNs, although information on the reasons behind this was not reported. ITNs/LLINs became a primary vector control tool in the Philippines and Namibia, and replaced IRS for six years in Bhutan (1998-2004), until cases doubled from 1998 to 1999, sparking a programme review and the introduction of several activities, including focal IRS to supplement ITNs. The programme had struggled to re-treat ITNs in a timely manner, which may have contributed to the increase in cases. Malaysia never switched from ITNs to LLINs because the programme believed that ITNs were sufficient. Malaysia also did not have external funding, such as a Global Fund grant, which may have contributed to the decision to continue ITN use. LLINs have been used to protect populations living or working in hard-to-reach or remote areas, such as parts of Bhutan and in the former conflict zone of Sri Lanka. NGOs in Sri Lanka that were familiar with the conflict-affected communities in the east and north distributed LLINs.

Similar to reporting on IRS coverage, comparison of coverage and its definition for ITNs/LLINs across case studies was challenging. Countries used different estimates, most based on net ownership rather than any measure of use, including the number of nets distributed as a proportion of the national total population or national population at risk. Only the Philippines case study report detailed the assumptions behind the LLIN coverage indicator. In the Philippines, coverage was defined as two people having an LLIN for an assumed net lifespan of three years. In Sabah, one of the most endemic areas of Malaysia, 55% of the high-risk areas were considered covered by ITNs in 2009. The distribution of ITNs then increased, from 56,000 in 2009 to nearly 80,000 in 2011, while continuing re-treatment of older ITNs. In Sri Lanka, LLINs were introduced in 2004 and by 2005 15% of the population at risk, approximately 440,000 persons, was considered to be covered (protected) by a LLIN, climbing to 35% by 2010. It was believed that the combination of IRS and LLINs in the country helped to lower receptivity. The Philippines programme first distributed ITNs in 1990, then LLINs were introduced in 2005, and by 2011, ITN and LLIN coverage in the 40 provinces that received funding from the Global Fund was 73% of the target. In Namibia, ITNs were first distributed in 1993 and then replaced by LLINs in the mid-2000s. By 2005, coverage ranged from 5-10% of the population at risk, increasing to 50% in 2009 and 2010, but dropped down to 30% in 2011. Mass distribution of nearly 500,000 LLINs in the northern regions was conducted in 2013.

Other alternatives have also been tested. The Philippines experimented with hammock-type LLINs for their military but they found the available design to be too difficult to climb out of so they were not scaled up. Hammock LLINs were found to be an effective tool for preventing malaria in forested areas of Cambodia, but this may be related to cultural factors, as villagers and forest workers in the area were used to using hammocks in the early evening hours [19]. In Sri Lanka, efficacy of insecticide-treated curtains was studied in the late 1990s but no scale up was reported.

ITNs/LLINs have been a core vector control tool for many countries, in particular for populations that are harder to reach with IRS. However, coverage estimates are difficult to compare across countries, and actual use has been difficult to estimate, thus it has been difficult to estimate the impact of ITNs/LLINs. Routine monitoring of coverage and impact of LLINs must be enhanced to better estimate their programmatic impact, especially on a more regular basis, to support locally relevant use of the nets.

5.4.6 Larval control

Larval control is defined as the use of substances that kill or inhibit the development of mosquito larvae or the introduction of fish or invertebrates that feed on larvae [20], and has been employed by all countries in the analysis. Larval control can include either larvivorous fish or larviciding (which includes both chemical and biological agents in water bodies to kill mosquito larvae).

Most countries started using larval control in the early years of their control programmes (1930s or 1940s) or during the GMEP campaign. Several of the case studies highlighted larval control as a strategy for outbreak or epidemic response (e.g., Bhutan, Malaysia, Mauritius, Turkey, Turkmenistan). In some countries larval control was used as a supplement to IRS, to cover areas that had low or phased-out IRS coverage (e.g., Cape Verde, Mauritius, Sri Lanka), or when zero cases had been reached and IRS was discontinued (Turkey, Turkmenistan). Coverage was typically measured by the number of persons estimated to be protected by this method but this was not detailed in most of the case study reports. When coverage was reported, it was measured in a variety of ways.

In the countries that have eliminated malaria (Mauritius, Turkey, Turkmenistan), larval control has been a continuous and important vector control method and is part of their POR strategic plans. In Mauritius, use of larvivorous fish was perceived to be useful when implemented in proximity to the airport (to lower receptivity in an area that may have imported cases) as well as in deeper rooftop pools and irrigation ponds where vectors were breeding. For the eliminating countries, there were differences in when and why larval control was used. In Malaysia, for example, it was used in low-risk areas throughout the year to keep receptivity at low levels; in contrast, in Namibia it was used primarily in the dry season, when there were fewer water bodies to treat. Sri Lanka used chemical larviciding in abandoned gem pits and wells. Difficulties in implementing larval control were noted throughout the case studies. In Namibia, perceived risk of poisoning animals impeded its widespread use, as did the cost. Inconsistent use of larval control (Philippines and Namibia), lack of intervention data reported to the central level (Cape

Verde), lack of breeding site maps (Mauritius), and lack of entomological surveillance in intervention areas (Mauritius) made it difficult to assess the impact of larval control on reducing receptivity or malaria incidence.

Effectiveness of larval control has been measured in Mauritius and Turkey. However, it was conducted in combination with other interventions (in Mauritius alongside IRS and fogging; in Turkey alongside IRS and environmental management) so it was not possible to identify the impact of larval control alone. Research on larval control undertaken in Sri Lanka showed reductions in vector density in the laboratory and in field sites, such as dams, gem pits, brick-making fields, and cement water tanks [21,22], but the study did not measure impact on malaria transmission.

Similar to IRS and LLINs, coverage of larval control has been measured in different ways across programmes. Countries measured larval control by coverage of larval habitats, hectares, reservoirs, or by the number of people protected, all of which are challenging to compare or understand the scale, much less the impact of this intervention. In Turkmenistan, 136 larval habitats and labour camps (in the early 2000s) were covered by larval control, and (in 2009) six hectares were treated with oil-based larvicides and 1,828 hectares were treated with fish. In Mauritius (1985), nearly 16,000 potential larval habitats were treated with temephos. In Sri Lanka in 2001 approximately one million people were estimated to be protected through the distribution of larvivorous fish, but by 2002 only 40,000 were considered to be protected.

As there are some countries that may rely heavily on larval control in the prevention of re-introduction stages, such as Sri Lanka, more rigorous monitoring, including stronger indicators, and measurement of impact is needed to understand the best settings for its implementation.

5.4.7 Environmental management

Environmental management activities aim to reduce the size of the immature vector population through habitat modification [20]. Environmental modification activities ranged across the case studies, depending on the *Anopheles* species and their preferred larval habitats: cleaning and drainage projects (Bhutan, some parts of Malaysia, Mauritius), marsh draining (Turkey), cleaning or flushing of stream or irrigation canals (Philippines, Sri Lanka, Turkey), infilling of unused reservoirs (Turkmenistan), intermittent drying of reservoirs (Cape Verde), protection of water tanks (Cape Verde), and filling of unused gem pits (Sri Lanka). Namibia did not list any of these activities.

Environmental management was used as a major intervention for five programmes (Turkey, Turkmenistan, Malaysia, Philippines, Sri Lanka) since the early 1900s. In Malaysia it was mainly used in West Malaysia. It was continued as a supplementary measure to IRS in Turkey and Malaysia, as an outbreak response measure in Turkmenistan, and part of the POR strategy in Mauritius. Coverage was not reported in the case studies.

In Mauritius, the large-scale draining/cleaning projects, in addition to other factors such as improvements to housing structures and urbanization, is credited with decreasing the level of malaria transmission before the initial malaria elimination campaign and helped to sustain lower transmission levels during the rest of the 20th Century. In the Philippines, stream clearing was used as a supplementary vector control measure, but had limited overall impact on case incidence, which may be in part due to its inconsistent use.

Similar to larval control, environmental management has been used by many countries as an ongoing vector control tool, and may become more important in the end stages towards malaria elimination. However, as with larval control, methods to monitor its impact on transmission need to be improved.

5.4.8 Personal protection

Four of the case studies reported having a strategy that included use of personal protection approaches, such as promotion of protective clothing, or insecticide-treated products and some without a strong evidence base, such as ingesting traditional herbal medicines. For example, in the Philippines, use of personal protective measures during evening activities was a recommended strategy, but the specific activities were not described. Namibia promoted awareness in the community of wearing protective clothing, and in one region the population traditionally used herbs as personal protection.

Personal protection methods may become more important in settings where outdoor-biting anophelines play or will begin to play a larger role in transmission, owing partly to vector replacement dynamics. Additional evidence is needed on the effectiveness of these tools on transmission reduction at the community level.

5.4.9 Economic development and development projects

Economic development was noted as a main contributor to declining receptivity across many countries as it catalyzed changes that impeded the breeding, feeding or resting behaviour of major malaria vectors. Economic development may have led to changes at individual household level (e.g., housing materials) or larger community level (e.g., large-scale construction projects, urbanization, increased access to medical care and services). Improvements in housing made indoor feeding more difficult, as anophelines were less able to enter and exit homes pre- and post-feeding. These improvements, including use of air conditioning by about 50% of households and villages, were likely contributors to a reduction in receptivity in Turkmenistan. Similarly, in Bhutan, electrification of homes and subsequent use of electric fans may have reduced transmission. Urbanization is another factor, in that it reduced the number and surface area of anopheline breeding habitats. Water bodies became dry or polluted in some provinces in the Philippines, leading to a decline in larval habitats, since the primary vectors require clear, clean, slow flowing water. For many case study countries, in particular in the Asia Pacific, primary vectors were forest dwelling. Increasing deforestation reduced vector-breeding habitats, such as in Sabah State of Malaysia, where the decline in forest habitat was believed to have reduced vector abundance of *Anopheles balabacensis*. Economic development in Mauritius in the 1950s and 1960s reduced malaria transmission, leading to the first malaria elimination campaign (1969) and helped to sustain lower transmission levels for the rest of the Century. Although receptivity may have declined in some countries, these transitions were also accompanied by increases in population movement or immigration into receptive areas, elevating the potential risk of transmission. This increased vulnerability due to risk of importation has affected Bhutan and Malaysia even while receptivity is declining.

While changes in economic or infrastructure development in some countries led to a decrease in receptivity, in some areas changes led instead to an increase in receptivity. Irrigation schemes increased levels of receptivity in several countries, such as in Turkey and Mauritius. Dam construction was thought to have increased receptivity in Sri Lanka, Turkmenistan and Bhutan. For example, in Sri Lanka, the 1987 epidemic was linked to a major dam construction project on the Mahaweli River, in the malaria-endemic eastern part of the country, which included forest clearing for rice cultivation. This change in land use resulted in an increase in receptivity, which increased risk of malaria for the one million settlers who moved there from non-endemic areas.

Cape Verde and the Philippines provide examples of the increase in receptivity due to human behaviour. In Mauritius, flat rooftops became popular after the 1960s but because of the pooling of water may have led to an increase in receptivity, as they provided good larval habitats for *Anopheles gambiae*. In the Philippines, the benefits of electrification in reducing transmission may have been offset in remote areas as more people stayed up later in the evening hours when vector exposure is greatest.

Some changes in development have accelerated malaria transmission or, in contrast, progress toward elimination. In either case, continuous measurement of receptivity will alert malaria programmes to changes in transmission dynamics. This measurement relies upon ongoing, robust entomological surveillance.

5.4.10 Combining vector control strategies

Most programmes rely on a combination of interventions, which together are believed to have reduced vectorial capacities and receptivity of the risk areas.

IRS was a primary tool for most programmes, along with ITN/LLIN to increase coverage of vector control and some type of larval control. Some countries credited the combination of interventions with reducing incidence or receptivity in their countries. In Mauritius, IRS, space spray and larviciding were used in combination with surveillance in active foci; non-active foci receive all interventions except for IRS. The programme attributed success to the control of larval habitats above all other interventions. In the Philippines, the combination of IRS and LLINs was credited for the significant drop in cases since the 1990s. In Turkey, the impact of vector control methods was used as a justification for the setting of a national elimination goal, with the plan to use IRS, larvivorous fish and ITNs to reduce receptivity and achieve elimination.

5.5 Discussion

In the elimination case study series, the scope of data collection was broad and not focused exclusively on vector control, which in some cases translated to a limitation in the comparability of results in the cross-case study analysis. Quality and coverage of vector control interventions was difficult to understand and to compare across case studies, limiting the lessons drawn across all the countries' experiences. Furthermore, assessment of the impact of vector control interventions was either not available or not fully explored in any of the case studies, most attribution of impact was anecdotal. Moreover, there was no possibility to explore counterfactuals to compare interventions, or lack of, when analysing what may have helped or hindered the programme. However, even with these limitations, the case studies were used as the primary data source as they were comprehensive and extracted information from national malaria program data, reports, and publications; WHO reports; malaria program reviews; and WHO and other historical documents.

Some common themes and lessons have emerged. The cross-case study analysis showed that most countries, both eliminating and POR, employed a similar range of vector control tools in the latest period of elimination. IRS was a primary vector control tool throughout the case studies, as most countries have continued this intervention since the GMEP era, when it was proven effective at reducing receptivity. However, there were several examples of programmes that rapidly scaled down IRS without evidence of any strategic planning or stratification process. It is possible that reductions in IRS were linked with a foci- and case-based (focal) strategy, where cases declined and then IRS was phased out. However, this was not clearly described. Instead, the declines in IRS documented in the case studies appear to be more related to a reduction in funding, personnel, programme capacity, or due to ongoing operational constraints. Several countries slowed or halted IRS and subsequently had outbreaks or epidemics. More information is needed on how and when countries should consider decreasing or halting of their primary vector control interventions, and how to maintain capacity to respond to outbreaks. 'Stopping' or 'slowing' rules for vector control, or guidelines on when programmes should scale down IRS or LLIN distribution or halt them completely, would be helpful to countries pursuing and reaching elimination.

Other tools used by most countries included LLINs, in particular to provide prevention for hard-to-reach populations (e.g., in remote or unstable and insecure areas, or areas with a high number of mobile populations). In some case studies, LLIN use was directly linked with access to external funding, such as from the Global Fund.

Larval control and environmental management were implemented by many programmes, however, coverage and effectiveness were not well described in the case studies nor was the articulation of rationale supporting their use. There was a lack of evidence of effectiveness of these tools in reducing receptivity or malaria transmission by programmes, likely because it was challenging to measure or studies where it did not show impact were not reported. There was also scant research undertaken to measure effectiveness of environmental management schemes. Larval source management (not including larvivorous fish), in selected circumstances, has been found to contribute to a reduction in malaria incidence [23]. There was only "low quality" evidence reported in the Cochrane Review on larvivorous fish, where there was variable evidence of the effect of larvivorous fish on the density of larvae or reduction in breeding sites with immature vector breeding, and no studies measured the impact of larvivorous fish on malaria incidence [20]. Notwithstanding, if countries choose to rely upon larval control instead of IRS and/or LLIN implementation as they approach elimination, more country-level and setting-specific evidence, based on rigorous evaluation, is still required for more consolidated conclusions [24].

The objective of implementing IVM was not well articulated by the malaria programmes, and the meaning of this strategy varied across programmes. While it means a combination of five components, most programs assumed that intervention combination was the main IVM strategy.

Countries in the case study series that have successfully eliminated malaria and are now in the POR phase had similar approaches. All POR countries used IRS and larval control as primary vector control measures. Two of the three countries that successfully reached elimination combined IRS with other interventions with the intention of reducing receptivity. POR countries had a more detailed description of the entomological surveillance activities undertaken, which appeared to be consistently implemented over time.

As entomological surveillance data should be the basis for all response interventions and programme strategies, consistent and high-quality data are needed [25]. Entomological surveillance was prioritized by some programmes, in particular in countries that are either close to or have achieved elimination. However, the response component of this surveillance, which could be used for outbreak forecasting, stratification leading to targeting of interventions, and longer term malaria programme strategy, was either not a programme intervention or was poorly articulated in the case studies. Information on insecticide resistance monitoring was scarce, with only a few reports of insecticide resistance and the program response. There were limited data on how entomological surveillance was conducted or the workforce needs, and no description of collaboration with reference or other research laboratories or training institutions. Linkage between the entomological and epidemiological data was not described, except in Malaysia, where one database combines both types of data. It is likely that most programmes were not taking advantage of these data to inform their intervention responses, coverage, timing or tools.

The choice of vector control tools in the case studies was not strongly linked to evidence. Although biologically plausible, the empirical evidence base on the effectiveness and cost effectiveness of vector control tools implemented, such as larviciding, environmental management and space spraying or fogging, remains weak. WHO does not recommend space spray [26]. Given that these interventions are implemented as part of integrated vector control strategy, it is difficult to conduct trials. However, countries embarking on introducing these interventions should consider incorporating rigorous operational research to gather evidence on the effectiveness and cost-effectiveness of these interventions.

Choice of vector control tools was not described as a response to the receptivity profile of the country. In fact the factors behind intervention choice were generally opaque across the case studies, leading to the assumption that there must be other background factors at play that are not articulated in the case studies. Global guidance, such as the 1993 WHO Global Malaria Strategy, likely informed some of these choices. Intervention cost, funding availability, and programme capacity required for distribution and operation of interventions were all likely factors at play, as well as cultural and historical factors.

5.6 Conclusion

Scaling up or down of vector control, in particular IRS, was not linked clearly with changes in stratification, epidemiology or operational information. In most cases declines appeared to be decided based on funding constraints rather than strategy. The scaling down of IRS contributed towards malaria resurgence in several countries, wiping out years of effort and progress. Countries must be able to make a case to policy and decision makers for continued investments in vector control in order to 'go the last mile' and attain and sustain elimination. Programmes must be able to link together quality entomological surveillance data, evidence-based real-time vector control response strategies, evidence on impact of vector control, and comparable coverage and quality indicators to make this case. The linkage between epidemiological surveillance data and vector control as part of the surveillance and response intervention is critical as countries move towards elimination and seek to prevent resurgence. This entails a much closer link between the eco-systemic and public health approaches in malaria control and elimination. An evidence-based stratification system, using risk and receptivity maps, would help programmes make the case for maintaining coverage of risk areas with expensive and time-consuming vector control interventions [27].

The GTS provides a strategy of the action needed to accelerate progress towards elimination and AIM when placed in the context of a given country, and provides the framework for policy and advocacy. The international malaria community can take forward these strategies and play an important role in filling in the gaps that are outlined in this analysis of country experience. More work needs to be done to fill gaps in programme guidance, providing clarity on the best methods for choosing and targeting vector control interventions, and then supporting countries in the next steps, which are measuring cost, cost-effectiveness and cost-benefit of vector surveillance and control interventions.

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CHAPTER 6

The central role of national programme management for the achievement of malaria elimination: a cross case-study analysis of nine malaria programmes

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6.1 Abstract

Background: A malaria eradication goal has been proposed, at the same time as a new global strategy and implementation framework. Countries are considering the strategies and tools that will enable progress towards malaria goals. The Eliminating Malaria Case-Study Series reports were reviewed to identify successful programme management components using a cross-case study analytic approach.
Methods: Nine out of ten case-study reports were included in the analysis (Bhutan, Cape Verde, Malaysia, Mauritius, Namibia, Philippines, Sri Lanka, Turkey, Turkmenistan). A conceptual framework for malaria elimination programme management was developed and data were extracted and synthesized. Findings were reviewed at a consultative workshop, which led to a revision of the framework and further data extraction and synthesis. Success factors of implementation, programme choices and changes, and enabling factors were distilled.
Results: Decentralized programmes enhanced engagement in malaria elimination by sub-national units and communities. Integration of the malaria programme into other health services was also common. Decentralization and integration were often challenging due to the skill and experience levels of newly tasked staff. Accountability for programme impact was not clarified for most programmes. Motivation of work force was a key factor in maintaining programme quality but there were few clear, detailed strategies provided. Different incentive schemes targeted various stakeholders. Training and supervision, although not well described, were prioritized by most programmes. Multi-sectoral collaboration helped some programmes share information, build strategies and interventions and achieve a higher quality of implementation. In most cases programme action was spurred by malaria outbreaks or a new elimination goal with strong leadership. Some programmes showed high capacity for flexibility through introduction of new strategies and tools. Several case-studies described methods for monitoring implementation quality and coverage; however analysis and feedback to those implementing malaria elimination in the periphery was not well described.

Political commitment and sustained financing contributed to malaria programme success. Consistency of malaria programmes depends on political commitment, human and financial resources, and leadership. Operational capacity of the programme and the overall health system structure and strength are also important aspects.
<u>Conclusions:</u> Malaria eradication will require adaptive, well-managed malaria programmes that are able to tailor implementation of evidence-based strategies, founded upon strong sub-national surveillance and response, with adequate funding and human resources.

6.2 Background
Global goals for malaria control, elimination and eventual eradication have evolved rapidly in the last year. A global goal of malaria eradication by 2040 was recently proposed [1], and at the same time, a new Global Technical Strategy for Malaria (GTS) was launched by WHO in 2015 and endorsed by all member states, providing the operational framework for achievement of elimination and stating an elimination goal of 35 countries by 2030 [2]. The overarching implementation and action framework, *Action and Investment to Defeat Malaria* (AIM) by Roll Back Malaria, was also launched in 2015 [3]. Many malaria programmes around the world are considering or committing to malaria elimination and are working to integrate the GTS and AIM principles into their national malaria programme strategy and framework. It is also likely that during this process, countries are considering the internal and external factors that may propel or impede progress towards elimination.

There are important challenges to address for both the long-term goal of global malaria eradication, as well as national elimination efforts. As highlighted in the GTS, countries must ensure political commitment and financing, and address major technical challenges, such as drug and insecticide resistance [2]. An overarching challenge at the national level is the inadequate performance of health systems. Deficiencies in health system structure may take the form of weak surveillance, inadequate tools for diagnosis and treatment, poor management of supply chains, an unregulated private health sector, weak monitoring and evaluation, and lack of adequate technical and human resource capacity. Ensuring that national malaria programmes have personnel with the appropriate level of programme management skills and tools to supervise and coordinate high quality implementation and evaluation is essential to achieving elimination, and, ultimately, eradication [2].

Today's eradication goal is not the first effort to rid the world of malaria. The first attempt was made during the Global Malaria Eradication Programme (GMEP) (1955-1970). However, there are some major differences between that programme and present day efforts. The GMEP was based on vertical, time-limited interventions deployed through mainly centralized health systems, where authority was held mostly at the national level. In contrast, today's health systems are mainly decentralized and malaria programmes are integrated into vector-borne disease control programmes [4]. While verticality brought some benefits, such as greater control and potential for motivation of staff, it also meant that activities were often not integrated with broader communicable disease activities, and lacked a clear, strategic component of surveillance with effective response packages, which created major challenges for achieving effectiveness and sustainability. Attrition of professional staff was increasingly a problem as

GMEP progressed; the work became rote and routine and less about problem-solving. Without strategies in place to maintain motivation, trained staff left country programmes [4]. In some cases, national programmes following GMEP guidance did not adequately build up systems in country for capturing epidemiological data that could identify changing transmission patterns, or failed to evaluate the impact of interventions, leading to campaigns that became unable to reorient or adapt to changing contexts [4]. In addition, there was no agenda for research and development to accompany the GMEP. Therefore, as technical challenges such as drug and insecticide resistance arose, solutions were not forthcoming [5]. As financing for malaria eradication was withdrawn in the 1970s and 1980s, progress toward eradication stalled.

The lessons from the GMEP, as well as the framework of the GTS and the AIM and the new eradication goal, all speak to the importance of strong programme management as a central component for the success of countries aiming to achieve malaria elimination. The Eliminating Case-Study Series by the WHO Global Malaria Programme and UCSF Global Health Group was developed to detailed comparatively describe, analyse and discuss examples of national malaria programmes that are currently eliminating or have eliminated malaria. Thus, the case studies series offered an opportunity to review programme management strategies and contexts across countries to identify success factors along the road to elimination. In this paper, the authors report the findings of this cross case-study analysis, which is the first of its kind to examine countries in different socio-economic, political and ecological contexts. This analysis focuses on the way in which countries have implemented elimination programmes, have developed and adapted their malaria elimination strategies, and how they have operated within the context of different political, financial and human resources.

6.3 Methods

This cross case-study review included nine of the 11 case-studies in the malaria elimination case-study series, produced through a collaboration between the WHO Global Malaria Programme and the Global Health Group, University of California San Francisco. Case-studies were included in the cross case analysis if they were in final English language draft at the time of analysis (November 2014). Case-studies included in this cross case analysis are Bhutan [6], Cape Verde [7], Malaysia [8], Mauritius [9], Namibia [10], Philippines [11], Sri Lanka [12], Turkey [13], and Turkmenistan [14]. Case studies from La Reunion and Tunisia were not included in this review because the report from La Reunion was not finalized nor translated into English at the time of analysis, and a draft of Tunisia was not yet available by the time the analysis was underway. Three of the nine case-studies represented countries in the prevention of reintroduction phase (Table 6.1), which have reached zero locally acquired cases and are actively preventing reintroduction of malaria [15].

Table 6.1: Case-study countries and elimination status

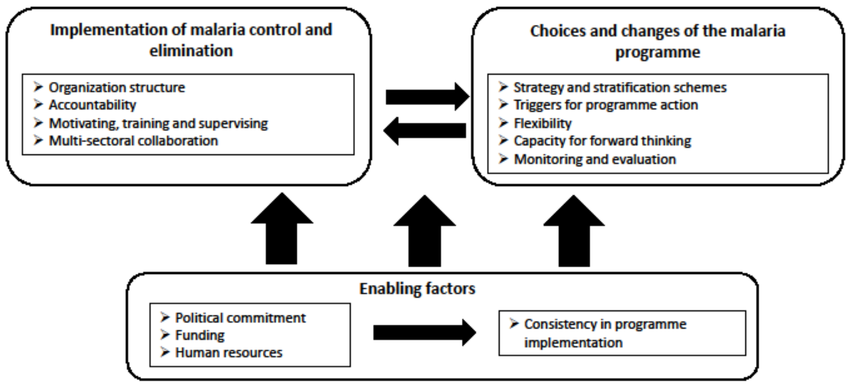
Country	BTN	CPV	MYS	MUS	NAM	PHL	LKA	TUR	TKM
Elimination Status	Eliminating [6]	Eliminating [7]	Eliminating [8]	Prevention of Reintroduction [9]	Eliminating [10]	Eliminating [11]	Eliminating [12]	Prevention of Reintroduction [13]	Prevention of Reintroduction [14]
Elimination History	Goal of zero transmission nationally by 2018; national malaria elimination certification by 2020.	Achieved zero cases 1968-72 but epidemic occurred during 1977-79. Second elimination attempt 1983-85, however epidemic occurred during 1987-88. Goal of national elimination by 2020.	Goal of national elimination by 2020: elimination in West Malaysia by 2015 and elimination in Sabah and Sarawak by 2020.	First eliminated in 1969 and received WHO certification in 1973. Resurgence in 1975. Second elimination achieved by 1998.	Goal of national elimination by 2020.	Strategy of progressive sub-national elimination with national elimination (all provinces) by 2025 (recently updated to 2030).	Near elimination in 1963, then an epidemic from 1967-68. Zero local cases reported since November 2012; will seek WHO certification by end of 2015.	Most of the country in consolidation phase in 1974, followed by epidemics in 1977 and 1993-1996. Last indigenous cases reported in 2012 during outbreak.	First eliminated in 1961. In most recent attempt, the last indigenous case occurred in 2004. Received WHO certification in 2010.

BTN: Bhutan; CPV: Cabo Verde; MYS: Malaysia; MUS: Mauritius; NAM: Namibia; PHL: Philippines; LKA: Sri Lanka; TUR: Turkey; TKM: Turkmenistan

An initial conceptual framework for programme management in malaria elimination was developed to provide structure for the cross case analysis (Additional file 1). This framework was based on a document review of malaria elimination guidelines, reports, consultations and manuals to identify historical and current policy and research on management strategies, tools, and operational research. The document review took place in 2013 and 2014. The documents reviewed for the development of the initial conceptual framework were found using the following search terms: "program management," "supervision," "decentralization," "vertical," "integration," "health systems," "incentives," "training," "financing," "costs," "human resources" and "malaria," "malaria control," "malaria elimination" in Pubmed and Google Scholar (English only). A list of these documents can be found in Additional file 2. The framework was formatted in Excel as a matrix (Additional file 1). Using the framework components, two researchers (CSG, GN), reviewed each case study report for information (e.g., examples, synthesis or analysis) on program experience for each concept. If there were examples for a given concept, the experience was summarized in detail in the corresponding matrix cell. If there were no examples, the cell was left blank. After reviewing a given report across all concepts, a summary of the experience with a note as to how strong of an example it was (by subjective assessment) was written into the cell. After all of the reports were reviewed and cells filled in, main challenges and weaknesses of each programme experience were summarized by the researchers.

A two-day workshop was held in 2014 to review the matrices on programme management and other themes. Malaria elimination researchers and experts conducted an in-depth review of case-study reports. Each reviewer read two reports and compared the information presented in the reports against the qualitative descriptions of experience, synthesis and analysis entered into the programme management matrix and summaries by CSG and GN to ensure that the data captured in the matrix were comprehensive, and to debate the lessons learned across the case-study experience. One of the results of the workshop was consensus that the framework needed revision to better capture the available data and draw firmer conclusions of major programme strengths and weaknesses. CSG combined the inputs from the workshop and additional documents collected (see Additional file 2) and re-reviewed to develop the new framework. The final conceptual framework for the analysis can be seen in Figure 6.1. The framework was structured as follows: 1) Implementation-how malaria elimination is made to happen; 2) Malaria programme choices and changes; 3) Enabling factors, and how these factors affect the consistency of implementation. Using this new framework, CSG conducted a second round of in-depth review of the nine case-study reports, data extraction, summary and analysis. Ministry of Health, malaria programme personnel or other stakeholders were not interviewed for this analysis; however, data collection for the original case-study reports was based on extensive key informant interviews in addition to the quantitative data collection.

Figure 6.1: Final conceptual framework



6.4 Results

6.4.1 Implementation

Table 6.2: Key learnings from implementation of malaria elimination programmes

• Most programmes operated in a decentralized health system, which in some cases led to greater engagement in malaria elimination by subnational health offices and communities. • Most programmes were integrated, where malaria programme services were delivered through the system of general health services. Integration was overall a negative experience for most malaria programmes because staff were often given too many roles and responsibilities that were not clearly defined. • During the early period of transition to decentralized and/or integrated programs, challenges were faced in maintaining quality and execution of interventions. • Accountability for programme impact was not clear for most programmes. • Motivation is important to maintain quality of interventions and different groups are and can be incentivized in different ways. • Sustained capacity building and strong supervision are key to successful elimination. • Working with other sectors to share information and develop and implement interventions has led to greater effectiveness in surveillance, prevention and targeting.

The ways in which malaria programmes were implemented were defined by several factors, including the level of decentralization and integration of the malaria programme, the health system in which the malaria programme operated, its organizational structure and the accountability of the programme.

Decentralization is defined as the transfer of authority or dispersal of power and responsibility in public planning, management and decision making from the national level to subnational levels [16]. Most general public health programmes operated within a centralized structure until the early 1980s, when budget crises and recognition of inefficiencies led to widespread reforms [17].

Most of the malaria programmes in the case-studies operated within an integrated national health system. Integrated, or horizontal, programme service delivery is the delivery of services through the system of general health services [18,19]. Vertical programmes, in contrast, are “directed, supervised and executed, either wholly or to a great extent by a specialized service using dedicated health workers”, an example of which is national smallpox eradication campaigns [18]. Most malaria programmes were integrated into curative health services provided by the national government, whereby malaria cases were diagnosed and treated in the national network of primary health care facilities. However the management and operations of the other malaria programme activities were often less clear. Some programme elements, such as surveillance and response approaches or prevention strategies through vector control, were conducted in a semi-vertical fashion by sub-national malaria-only units run by malaria regional officers or malaria technicians in basic health units. In other countries, integration with other vector-borne diseases translated to sub-national offices that coordinated vector control for all vector-borne diseases, using the same funding and personnel to conduct vector control for dengue, malaria and other diseases. Refer to Table 6.2 for a summary of the key learnings from implementation of malaria elimination programmes.

Table 6.3 shows the type of organization and level of integration of disease control within each country with estimated time frame of when these processes were underway. Table 6.3 also includes a measure of the clarity of accountability within each malaria programme, which was an assessment based on the information in the case-studies on the responsibility for progress or impact, decision-making, and funding flow structure of each malaria programme.

Table 6.3: Level of decentralization, integration and clarity of line of accountability affecting the national malaria programmes of the nine countries, with year of decentralization and integration if available.

	Centralized vs. decentralized health system	**Vertical vs. integrated malaria programme**	**Clarity of line of accountability as described in the case-study** 0, +, ++**
BTN	Decentralized since 1981 to district; further delegation from districts to subdistrict level beginning in 1990 and scaled up by 1996	Integrated with other vector-borne diseases since 2003	0
CPV	Decentralized to "Health Delegation" (local health authority) level	Integrated with other infectious diseases	0
MYS	Decentralized to the state level	Integrated malaria programme since 1981 (national) and 1986 (Sabah and Sarawak)*	+ Funding and decision making mainly originated from the central level, while the states were also held accountable for the impact on the ground
MUS	Decentralized	Semi-vertical malaria programme structure; malaria programme was integrated into the public health system in 1968	++ Semi-vertical malaria programme translated to most accountability resting with the malaria division of the Communicable Diseases Control Unit at the national level
NAM	Decentralized	Integrated malaria programme structure since inception in 1991*	++ National level appeared to be most accountable
PHL	Decentralized starting in 1958, implemented thoroughly in 1990s	Integrated malaria programme with health services since 1982, however some vertical elements (regional and sub-regional malaria specific positions) remain	++ Local level malaria programmes were relatively autonomous and accountable for the progress of malaria control, however there were nationally-funded personnel in each province to supervise and monitor activities but with no decision-making authority
LKA	Decentralized since 1989	Malaria is integrated with other vector borne diseases and with curative services through health system structure	++ National office appeared to be mainly accountable, however district malaria officers were responsible for malaria implementation and impact in their districts and reported to both the

			national programme and regional director of health services
TUR	Centralized system; Ministry of Health responsible for health care and social welfare activities, supervises all medical and health care personnel in the public sector; Education and health services are provided by the central government	A vertical malaria network was developed since 1920s with three levels: 1. National Malaria Commission (national level); 2. Province/district level with laboratory and headed by a physician with staffing of other malaria control personnel; 3. Peripheral level (subsections or "circles" of 10-15 villages), with personnel for vector control	++ The Directorate of Malaria Control was accountable for malaria strategy and achievements
TKM	Not clarified in case study, but assumed to be centralized	Most likely semi-vertical; The Sanitary Epidemiological Service (SES) responsible for communicable disease control including anti-malarial interventions; national, provincial and district level SES offices; SES considered specialized in malaria control, and works with the general primary health care services for malaria interventions	++ National-level SES appeared to be accountable for the impact of the malaria programme

BTN: Bhutan; CPV: Cabo Verde; MYS: Malaysia; MUS: Mauritius; NAM: Namibia; PHL: Philippines; LKA: Sri Lanka; TUR: Turkey; TKM: Turkmenistan.

0=not clear; + moderately clear; ++ clear.

*No further information provided in case-study report as to the type of integration of the malaria programme.

** The measure of the clarity of accountability within each malaria programme was an assessment based on the information in the case-studies on the responsibility for progress or impact, decision making, and funding of each malaria programme.

In addition to the role of integration, decentralization and accountability, implementation was also impacted by the motivation package for malaria workers, structure of incentives, training programmes, and supervisory structure offered by malaria control programmes. The role of intersectoral collaboration and its impact on malaria elimination was further explored.

Impact of decentralization on malaria programmes

Overall there were numerous examples of the decentralization process creating challenges for the implementation and quality of malaria control, with possible contribution to increases in incidence during the transition period when decentralization was first implemented. However, once in place, and roles and responsibilities were clearly assigned, in most cases decentralization increased local level capacity of the malaria programme as well as community access to health services. Across the case-studies, vertical programmes operating in a centralized health system (such as Turkey and Turkmenistan) appeared to have the clearest lines of accountability and assignment of roles and responsibilities, as there was one level responsible for both elimination strategy development and outcome measurement. However, in more complicated settings, some case-studies clarified well which office or person was ultimately accountable for programme operations and impact (Table 6.3). In Malaysia, decentralization was seen as benefiting elimination. While the malaria programme at the national level developed policy, provided technical expertise, and controlled the finances, each state and district had a vector-borne disease programme office which managed, coordinated and implemented malaria activities. The programme engaged state offices in the elimination planning by holding elimination workshops. Additionally, the malaria programme believed that the development of sub-sector offices, or malaria offices in remote localities in Sabah State had a substantial impact on reducing malaria morbidity by facilitating integration of the malaria programme into communities. Through engagement with the local level, there was a greater level of accountability sub-nationally for implementation of the malaria programme and its impact on the ground. However, funding and decision-making appeared to mainly rest with the national level.

In contrast, decentralization in Cape Verde appeared to impede malaria programme progress, mainly because capacity was low at the Health Delegation (local health authority) level and there were few resources or capacity for the central malaria programme to supervise or implement activities in the peripheral areas. Accountability for the quality and impact of programme activities was not clear.

Decentralization led to both positive and negative outcomes for the malaria programmes. In the Philippines, the process of decentralization led to a seemingly chaotic malaria programme environment in the 1980s and 1990s. At certain points, provincial and municipal level authorities were not able to lead malaria control efforts because of insufficient training and resources. There was a high degree of variation across provinces in quality and extent of implementation, NGO involvement, and external funding. In Laguna Province, for example, devolution in malaria free areas disrupted progress as malaria personnel were reassigned to other activities. This led to a disruption of the surveillance-response system and created a vacuum of experience when an outbreak occurred, which then threatened to spread into other receptive, malaria-free provinces where capacity was also inadequate. However, the positive impacts of decentralization included an increase in provincial, municipal and community ownership of malaria, eventual growth in staff and skills based in the field and a tailored approach to malaria control and elimination. Department of Health (national level) staff were positioned in each province to supervise and monitor activities, but they were not given decision-making authority. Local, sub-national staff appreciated this autonomy and turned to higher levels only when in need of technical guidance.

Bhutan's decentralization process was also relatively disorganized in the early years, when districts began managing the delivery of basic services. Malaria incidence rose from 5,213 cases in 1983 to 18,368 in 1984. The increase in cases was believed to be the result of a decline in indoor residual spraying (IRS) coverage and quality. However, once the process was more established, decentralization may have contributed to longer term reductions in malaria cases through an expansion of facilities and deployment of malaria workers in health centers in endemic areas, boosting surveillance activities.

In Sri Lanka, decentralization may have also contributed to an initial rise in malaria-related incidence and deaths. From 1990-99, when the system was undergoing the transformation, confirmed infections rose from 142,294 (1995) to 264,549 (1999). Then, from 2000 onward, incidence declined. The national programme formulated malaria control policy, monitored national malaria trends, provided technical guidance, and undertook entomological and parasitological surveillance. District-level offices coordinated parasitological and entomological surveillance, vector control, and conducted supervision and M&E activities. Even with the initial challenges, decentralization may have contributed to stronger leadership at the district level and local adaption of the programme. Accountability mainly rested with the national office; however, district malaria officers were also held accountable to the national programme.

Turkey's centralized health system may have contributed to the consistent approach of the public health services, and the maintenance of skills, capacity and malaria control activities over time. Challenges included staff shortages for active case detection in certain parts of the country. Staff were often transferred from areas where transmission had been interrupted to areas with current transmission, leaving malaria-free areas vulnerable in the event of resurgence.

Turkmenistan's centralized health system may have also led to a greater degree of consistency in the programme, accountability at the national level, and political support. However there were challenges in the programme, including delays in diagnosis, treatment and reporting in rural areas.

In Namibia, the national malaria programme provided funding, trainings and commodities to the regional level, which coordinated district activities. Due to the fact that donor funding for malaria almost exclusively moved through the national programme, accountability rested mainly at the national level.

The Mauritius case-study described its malaria programme as semi-vertical and the bulk of malaria personnel sat in the national office. Accountability for programme implementation and impact rested mainly at the national level.

Impact of integration on elimination progress

The impact of integration on malaria control efforts was overall considered negative, mainly due to overburdening staff with often-undefined roles and responsibilities. There was also a risk that the integrated programme would dedicate fewer resources to malaria when cases were reduced. The potential positive outcome of increased programme efficiencies and cost savings through integration (e.g, with all vector-borne diseases) was not documented in the case-studies.

Bhutan, Sri Lanka and Cape Verde provided clear examples of malaria programme integration with the transition from single-disease to multi-purpose technicians. In Bhutan and Sri Lanka the impact of integration was just occurring at the time of data collection and its impact was not described. Before integration, malaria technicians in Bhutan posted in hospitals and basic health units were responsible for all malaria diagnosis, treatment, and parasitological and entomological surveillance and vector control. Sub-national Health Delegates in Cape Verde became overloaded as they were responsible for clinical and administrative duties in addition to supervising the team of health technicians responsible for coordinating interventions and surveillance.

In Mauritius, the immediate integration of malaria control into the general public health services once the last indigenous case was detected in 1968 was likely a contributing factor in the resurgence of cases in the 1970s. Medical officers were newly responsible for malaria in their districts. These rapid transitions contributed to poorer quality passive case detection, lack of participation by health workers in malaria screening programmes, and financial constraints after integration.

In Namibia, integration similarly presented logistical and bureaucratic hurdles: one example was that drivers were not available for malaria related activities because they were busy with other Ministry-related tasks.

Malaysia’s integration of the malaria programme occurred after 1981, when elimination was declared infeasible. The malaria programme was integrated with other vector borne diseases at the central and state-based offices. Since dengue was the most common notifiable disease in 2010, it is likely that integration diverted resources away from malaria programme activities. Turkey provided a contrasting example of a vertical malaria programme. It appeared that the programme’s verticality led to a greater level of consistency in programme activity and resources, and translated to clear accountability at the national level for malaria strategy and achievements. However, during the epidemics recorded in the 1970s and 1990s, a contributing factor was waning interest in malaria control as the caseload became very low. It is theoretically possible that an integrated programme would been more flexible and cost-effective, able to shift staff or resources as needed across programmes.

The Philippines and Turkmenistan reports were not specific about the level of integration of the malaria programme.

Motivation and incentives

Maintaining a high level of motivation in implementers is important to sustain consistency and quality of interventions. Staff motivation is an important aspect of human resource capacity, and depends on a number of factors: working conditions, financial incentives, correct and prompt compensation, management of staff and possibilities for professional advancement [20]. This basic motivation package is often the key to a successful malaria programme. As malaria cases decline, different strategies must be employed to keep staff committed, and prevent turnover and loss of institutional knowledge. Incentives may be used if specific and predetermined milestones are achieved. Incentives are the “rewards and punishments that [service] providers face as a consequence of the organizations in which they work, the institution under which they operate and the specific interventions they provide” [20]. Community level and political motivation is also a key predictor of malaria elimination success, and can be significantly enhanced by including elimination targets and legislation. The case-studies described structures and mandates that motivated and incentivized communities or other sectors to engage in malaria elimination. Professional incentives were in place for volunteer health workers, but not described for malaria programme workers.

In Sabah State of Malaysia, Primary Health Care Volunteers (PHCV) were motivated by the prospect of professional work. PHCVs played an important role in diagnosis, treatment and prevention. IRS spraymen were often recruited from the PHCV pool, offering the possibility of a future paid position. Similar to the Sabah programme, the Philippines used incentives for the work of the paid Barangay (i.e., village) Health Workers. In addition to earning a small wage and an important role in the community, their microscopy skills and responsibilities were highly regarded among the primarily uneducated women who participated in the programme, who otherwise had limited employment opportunities.

The structure of external grant funding in the Philippines inadvertently led to a shift in non-financial as well as financial motivation in municipal staff. When the Global Fund grant support began in Apayao Province, the grant was structured such that municipality offices were given responsibility for planning and management, which translated to an increased level of motivation of municipal staff to take initiative and ownership of malaria control, with the positive affect of an increase in level of confidence for managing the malaria programme activities.

External grant funding increased the level of motivation to conduct comprehensive field work in Sri Lanka, because that funding covered travel costs and per diems for intensive entomological surveillance and supervision. However, delays in payment for the overtime or traveling claims counteracted the potential beneficial impact of these incentives.

The Sabah State malaria programme’s collaboration with private sector plantations (e.g., palm oil plantations) showed the motivating factors for plantations to get involved in malaria control. Plantation owners provided malaria diagnosis and treatment and some also provided vector control (either directly or through support to the district malaria programme office) because they believed the benefits of the collaboration to be an increase in plantation worker productivity and reduction in worker health care costs, an increase in their profile as a good place to work by providing access to health care and prevention on site, and abiding by expectations in Malaysia for corporate social responsibility and adherence to the labour laws.

Mauritius programme staff considered their public health laws enforcing environmental management and access to homes to conduct vector control to be motivating factors for community acceptance and participation in the malaria programme’s vector control activities. Certification schemes kept motivation at higher levels in Turkmenistan and the Philippines. Turkmenistan created a certification for laboratory quality, for which every laboratory participated in a scoring system for diagnosis, and labs exceeding an 80% score received a one-year certification. One example of an overarching elimination-friendly structure is the Philippines subnational elimination certification process, where provinces were reviewed and validated as “malaria free.” This structure was thought to have motivated provincial staff and community participation in malaria control.

Bhutan and Cape Verde did not report on incentives. Namibia’s programme found difficulty in recruiting support to and engagement of communities because their health volunteers were not motivated through financial or professional incentives.

Training

Training is an important component of a malaria elimination and POR programme. While there was very limited information in the case-studies on the coverage and consistency of trainings, several country experiences showed the risk of weakening the malaria programme when training programmes became infrequent or inadequate. Conversely, programme activities were strengthened when training was increased with the injection of external funding or if an outbreak occurred. The content and format of trainings were not well described and appeared to be weakly structured in the case-studies, and there was very little information on surveillance and response training. Most programmes did not describe on-the-job training formats, so it is assumed that they were large, seminar-style trainings.

There were several countries with inadequate training programmes and resultant operational challenges. Because training in Namibia was insufficient, quality of diagnosis and treatment services, record keeping, coordination, time management and communication were suboptimal. These problems were exacerbated by poor job descriptions. In the Philippines, lack of training and follow up when a new drug policy was rolled out meant that some staff were unaware of the new policy and how to implement it. Inadequate surveillance training in Turkmenistan weakened the programme in the 1990s and contributed to the outbreak of 1998-99. The problem was exacerbated by understaffing, in that many Russian specialists left the country after independence in 1991. Post outbreak, the programme increased capacity with the development of a continuous education programme (2004-10), reaching more than 1,400 personnel. In 2010, 11-20% of the government malaria budget was spent on staff training.

Global Fund grants provided funds to increase the number of trainings in Bhutan, Philippines and Sri Lanka. Sri Lanka held regular trainings to maintain engagement in elimination. Philippines' trainings led to improvements in planning and delivery of interventions.
Bhutan, Cape Verde, Malaysia, Sri Lanka and Turkey prioritized microscopy training to ensure that diagnosis skills were maintained as malaria cases declined.

Supervisory structure
Supervision of malaria control activities is conducted to ensure the quality of interventions and to increase or maintain a high level of motivation in the workforce [21]. Effective supervision should include regular visits to the periphery and activities to check information and supplies, problem-solving with the employee, and a feedback mechanism to encourage improvement [21]. In the case-study reports, supervision of intervention quality, timing, coverage and measurement of impact were not described. Resource constraints in some programmes limited staff time and transportation to carry out supervision of field activities.

In some case-studies the planned (though not necessarily executed) supervision structure was reported. In Bhutan, the malaria technicians supervised village health workers and health centers. The Sanitary Epidemiological Service (SES) of Turkmenistan, which was overseen by the Deputy Minister of Health, monitored coverage and performance of all interventions. In both Bhutan and Turkmenistan, the quality assurance process and supervision of microscopy were highlighted as key activities.

In the Philippines, Department of Health representatives at the provincial level were reluctant to supervise as the local staff worked autonomously. Thus, provincial authorities viewed health workers and local staff as partners and supervision in the traditional sense did not occur.

The Namibia and Sri Lanka programmes provided timeframes for supervision. In Namibia, national staff planned to conduct annual regional supervisory visits, regional staff conducted quarterly district visits, and district staff visited clinics on a monthly basis. Sri Lanka's Regional Malaria Officers aimed to visit all district entomological surveillance, IRS programmes, and up to two active case detection activities each month.

In Sabah State of Malaysia, state and district level entomologists supervised insecticide treated net (ITN) and IRS programmes conducted by district and sub-district offices. The national level laboratory supervised all microscopists and provided retraining for those who committed frequent mistakes. District level malaria officers supervised health volunteers.
In Mauritius, IRS activities by public health staff were "strictly" supervised by the team. IRS was conducted for two years within 500m of a case's residence.

In some countries, resources were not sufficient to maintain adequate supervision. Lack of transportation and limited staff in Sri Lanka cut down the amount of field supervision in recent years. There was little funding or time available for Cape Verde’s 17 Health Delegates to supervise the network of primary health facilities and health technician teams. In Namibia, a supervisory structure existed but was not followed due to time constraints and unreliable transportation. In Sri Lanka and Namibia, the injection of Global Fund grant funding increased the resources for supervision.

Multisectoral collaboration

The case-studies provided examples of multisectoral collaboration, where malaria programmes worked or planned to collaborate either with other Ministries in the government, such as the Ministry of Labour or Foreign Affairs, or other, non-health sectors including private sector health facilities or extractive industries. This type of approach is different from programme integration with national curative or preventive services, but can work well within that structure. Resurgences in several countries may have been prevented by identifying risks, sharing information and collaborating on malaria education and control with other ministries and the private sector. Contracting out services to private entities, which was done by some countries, may be cost-effective and increase quality and coverage. There were no experiences documented of programmes working with small enterprises or local chambers of commerce. The Bhutan malaria programme reported a need to involve other Ministries because of economic development activities and related migrant labour entering the country. Cape Verde developed collaborations with the Ministry of Agriculture and Environment, to improve agricultural practices and the management of rural water sources.

Some programmes outsourced malaria control implementation to NGOs. Namibia and Angola launched the Trans-Kunene Malaria Initiative (TKMI) in 2009 to monitor cross-border importation and coordinate communication, activities and policies. An NGO provided the funding and support for long-lasting insecticide-treated net (LLIN) distribution and monitoring along the border area. An NGO in the Philippines became the Principal Recipient of the Global Fund grant in funded provinces. In Sri Lanka, LLIN distribution in the conflict-affected areas of the country relied upon local NGOs, as they had community based ties to the region and were able to operate in areas that presented major challenges for the malaria programme.

Several case-studies presented examples of collaborations with private sector plantations or construction companies. During its first elimination campaign, Mauritius collaborated with private sugar companies to educate employees about malaria prevention and to create private clinics for screening and case reporting. More recently, the Sabah State malaria programme in Malaysia developed informal partnerships with private sector plantations. Plantation owners contributed resources by building subsector offices or clinics for malaria programme workers and contracting out or conducting IRS for plantation structures. Leaders of Apayao Province in the Philippines worked with local mine and mill operators and dam construction companies to identify projects that would increase the flow of migrant labour in high malaria risk areas and to develop joint screening and reporting systems. In Turkey, the malaria programme monitored irrigation systems.

Turkmenistan had a similar challenge, where there was an increase in vulnerability to malaria transmission due to military training activities and migrant worker mobility, both of which contributed to the outbreaks of malaria in 1998-99 and 2002-2003. Vulnerability is the proximity to malarious areas or resulting from the frequent influx of infected individuals or groups or infective anophelines [15]. In response, in 2005, the Chairman of the Cabinet of Ministers of Turkmenistan approved several documents calling for intersectoral collaboration and implemented plans including collaborating with the Ministry of Defense to share information, immigration services, and construction and oil companies that import labor to provide health information, free access to diagnosis and treatment.

6.4.2 Malaria programme choices and changes

Most case-studies documented the development of strategic plans and strategies for targeting interventions. Some programmes showed a high degree of flexibility and forward thinking. Surges in action by programmes were often reactionary and not a result of robust planning, and there were gaps in many programmes in monitoring and evaluation, particularly in the provision of feedback to the lower levels of the health system. Table 6.4 provides key learnings for programme choices and changes.

Table 6.4: Key learnings from malaria elimination choices and changes

- Strategic plans and stratification strategies are an important part of programme planning
- In most cases, programme action occurred as a result of an increase in malaria cases or deaths. In a few cases, a new elimination goal or leadership drove action.
- Some programmes showed a high degree of flexibility and adoption of new strategies and tools.
- Programmes likely avoided outbreaks by working with other sectors to identify and respond to threats of importation or increased incidence.
- Analysis and feedback of programme performance to the periphery is important but not well-described in the case-studies.

Strategic plans

The case-study reports had limited information on programme strategies and activities, and how they were designed. Five case-studies reported on the national strategic plan objectives and planned interventions (Bhutan, Cape Verde, Philippines, Turkey and Turkmenistan). It is assumed that all countries had strategic plans for control and elimination, but these plans were not described in the case-study. Most reports did not indicate whether the specific strategies were followed, or whether there was 100% compliance in coverage and timing. This is discussed in the M&E section.

Stratification

Stratification plans assist malaria programmes in targeting interventions and managing threats of increased receptivity or vulnerability. Receptivity means there is presence of anopheline vectors and existence of other factors favoring malaria transmission [15], while vulnerability describes the risk of malaria importation. Stratification plans may be based on disease epidemiology, entomological data, and socio-economic and development factors, such as development projects or population movement. Five case-studies included a recent stratification system (Table 6.5). Although the spatial scale and categories used in the stratification systems varied greatly, these systems identified priority areas for programmes to dedicate resources and response activities. Overall, a major gap in stratification plans across the case-studies was the surveillance and response strategies developed to mitigate the threat of vulnerability.

Table 6.5: Stratification systems, last year of update, and spatial scale

	BTN	CPV	MYS	MUS	NAM	PHL	LKA	TUR	TKM
Listed stratification system in case study	Yes (classification + activities)	No	Yes (classification only)	Yes for period 1979-1982.	No	Yes	No	Yes	No, but information on type of foci classification and response detailed.
Last year of updated stratification system	2012	No info	2008, was planned for 2013	No info	No info	1996, 2010, 2013	As of 2010, stratified case based interventions to be designed	In place from 1977 onwards (through to publishing of case study)	Focus register established and updated (2004-2010)
Spatial scale	District	Foci have not been "properly explored, delimited and classified"	"Locality" (e.g., village, plantation section, or housing area)	"Locality" in which at least one local case had been detected (1975-1981)	Region	Provinces, based on indicators at barangay (or village) level (e.g., number of barangays with cases)	Presumably by district.	Strata are a collection of provinces. Foci also used, and defined as minimum unit of anti-malarial activities. Focus registered maintained at province level	Focus, minimum unit of malaria control action (e.g., one settlement)

The spatial scale used in the stratification systems varied across the countries. Some countries used the WHO foci classification system, which is currently comprised of seven categories of transmission foci (new potential, new active, endemic, residual active, residual non-active, cleared up, pseudo focus) [15]. The POR countries of Mauritius, Turkey, and Turkmenistan reported using the foci system. Bhutan used a district-level stratification system, but in 2012 adapted the foci-based system using six categories (endemic, residual active, residual non-active, new active, new potential, cleared-up). Mauritius used three categories (active residual foci; active new foci with more than three cases; active new foci with less than three cases). Other countries employed different spatial or descriptive scales. “Localities” in Malaysia were described as a village, section of plantation or housing area. Other countries used district or regional administrative units. In the Philippines, the unit of administration was the province, but the category of risk was defined at the barangay (village) level and aggregated up to the province level.

Only the Malaysia and Turkmenistan reports described how the programmes developed their stratification system. Malaysia reviewed incidence over three years, vector receptivity, and access to the health system. Turkmenistan reviewed case investigation and surveillance data combined with the malaria foci record “passports”, which included mapping. Programmes updated their stratification systems from every three years up to every 30 years or more.

The stratification strategies in Mauritius, Philippines and Turkey outlined response activities to be applied in each strata. The malaria programmes with clear stratification criteria, indicators and vector control targets appeared to benefit from these systems. Stratification was viewed as extremely helpful by the Philippines programme and in Turkey was believed to have facilitated appropriate decision making for the application of vector control. Namibia’s stratification system allowed for targeting of resources to priority areas; however the risk of importation and onward transmission in some areas was likely underrepresented. In Sri Lanka, epidemic forecasting based on entomological surveillance identified areas for mobile surveillance clinics and focal IRS.

Programme action

Some malaria programmes were spurred to action in response to increasing transmission, an outbreak or an increase in mortality. In most cases, these events were caused by waning surveillance or control, precipitated by a weakening of the surveillance and response system, which subsequently required a ramp up of resources and programme intervention. In other cases, surges in action were the result of leadership at the national or subnational level.

In several countries, a gradual decline in programme efforts led to outbreaks, which in turn encouraged programmatic action. Turkey did not plan for potentially increasing transmission when major irrigation projects were underway and increases in migration were expected. These factors contributed to an outbreak in 1977. In response, the programme was given a larger allocation by the government, surveillance agents and microscopists were hired, and laboratories received more funding. Turkmenistan saw an increasing level of vulnerability to malaria importation along the border with Afghanistan, and this risk was compounded by delays in diagnosis, treatment and reporting of malaria cases in some rural areas. These factors led to an outbreak in 1998-99, the response for which was an immediate increase in consumables for diagnosis and chloroquine and primaquine for radical treatment and chemoprophylaxis. A reduction in transmission followed. In Cape Verde, multiple outbreaks have occurred after IRS was reduced or halted; each outbreak triggered a surge in IRS coverage. The efforts, though, were not maintained as evidenced by the locally acquired cases recorded nearly every year. In 2006, an increase in mortality to eight deaths led to an investigation by the Cape Verde Ministry of Health and development of a new national goal of malaria elimination by 2020. In Malaysia, outbreaks in plantation areas of Sabah State stimulated several inter-sectoral private-public partnerships with plantations which included surveillance and vector control activities.

In several countries, endorsement of an elimination goal by government leaders led to programme action. When malaria elimination was adopted in the 1940s and re-adopted after its resurgence in 1975, the Government of Mauritius organized a military-like offensive. Philippines provided a similar example, but in a highly decentralized context, where in certain provinces motivated leaders augmented malaria screening and other control efforts by increasing staff and funding for the activities. In Namibia, action was spurred by the leadership of the former Minister of Health.

In some countries, programme activities continued consistently, without such surges in action. After experiencing a resurgence in the 1970s, Sri Lanka maintained entomological and parasitological surveillance activities, which informed programme activities and response strategies. Bhutan also had relatively consistent programme implementation.

Flexibility of malaria programme strategies and approaches to problem-solving
Several countries showed a high level of flexibility by introducing new or adapting strategies, from insecticide rotation to lessen the risk of insecticide resistance, to an increase in parasitological screening in development areas to curtail the risk of transmission, to collaborations with the private sector. The case-studies did not have detailed information on the process undertaken to evaluate or adapt new strategies.

Sri Lanka, Bhutan and Malaysia showed evidence of flexible programming. Sri Lanka introduced a series of programme changes in the 1990s, including the introduction of targeted IRS to replace “blanket”, or universal, spraying, partly in response to new WHO recommendations [22]. IRS insecticide rotation was introduced in 1998, for which different types of insecticides were used in bordering districts with rotation of insecticides across districts over time in order to lessen the risk of resistance. Farmer Field Schools were developed in the late 2000s, building awareness about the connection between insecticide use for agriculture and for disease management. Then, between 2000 and 2011, primaquine for radical cure of *Plasmodium falciparum* infections and RDTs for mobile malaria clinics were rolled out. In 2009, as the country progressed toward elimination, a series of changes to its parasitological surveillance programme were introduced. Bhutan similarly instituted a series of surveillance and response activities, including parasitological surveillance, mapping and response measures starting in 2013.

The malaria programme of Sabah State of Malaysia also showed flexibility. In the mid-1990s, Sabah State responded to the need at the community level for better access to diagnosis and treatment by recruiting and training primary health care volunteers. In 1995, volunteers collected 14% of the blood slides taken in the state.

Adoption of an elimination goal spurred the design and scale up of surveillance activities and integrated vector management (IVM) in Turkey, to be used in active foci and in emergency situations. The Ministry of Health supported these new strategies through decrees, regulations and guidelines.

Turkmenistan showed adaptive capacity in its response to two outbreaks that occurred post-elimination. A suite of epidemiological, treatment and entomological surveillance interventions and policies were rapidly executed in response to the 1998-1999 outbreak, along with monitoring and supervision by the national programme. However another outbreak occurred within three years (2002-2003), meaning that these measures were likely not sustained. The outbreak of 2002-2003 led to a similar scale up of interventions and surveillance, and also led to sweeping changes to strengthen the whole malaria control system starting in 2004.

The programme in Mauritius appeared to stay consistent over time. During the period of resurgence, the programme showed flexibility in that it was able to mobilize a large number of staff. The Cape Verde and Namibia case-studies did not contain specific examples of flexibility in the malaria programme.

Programme capacity for forward thinking

Malaria programmes in the case-study series did not show a high level of capacity for anticipation of threats to elimination. There are many examples of major development projections that combined a potential for increased receptivity and vulnerability. In general programmes either did not identify these challenges in advance therefore did not have adequate or timely responses to these threats, or they were unable to secure funding to mitigate the impact. In either case, there appeared to be a lack of coordination with other sectors. In the few examples where programmes did work with other sectors, it appeared to help avoid outbreaks or epidemics.

Several malaria programmes did not anticipate the increased risk of malaria transmission posed by irrigation and reservoir projects. In Sri Lanka, dam construction and forest clearing for rice cultivation in the malaria-endemic eastern part of the country likely increased receptivity and led to the epidemic of 1987. There was no documented action by the malaria programme, nor was there evidence in the case-study that resources were increased, to offset these risks, and the epidemic grew to 687,599 cases by 1987. Reservoir construction in the 1980s and 1990s in Turkmenistan also led to increases in receptivity as the filtration ponds increased anopheline breeding habitat. At the same time (1980s), the dissolution of the Union of Soviet Socialist Republics (USSR) increased population movement into the country from Afghanistan, where malaria endemicity was higher. These developments contributed to the outbreaks in the 1990s.

The epidemic of 1977 in Turkey, which took place only three years after the country reported its last indigenous malaria case, was caused in part by an extensive irrigation project which increased breeding habitat and the level of internal migration from higher transmission areas in the eastern part of the country. However, the programme did not increase its surveillance efforts and by 1977 there were 115,512 recorded *Plasmodium vivax* cases. A second epidemic occurred in 1991, even though the irrigation canals were covered to prevent mosquito breeding. The programme did not adequately respond to large-scale internal migration from remote, endemic rural areas into the irrigation project zone, nor account for the flow of migrants from neighbouring countries, many of which were not politically stable and some of which were experiencing *P. vivax* epidemics. There were an inadequate number of malaria personnel in the affected areas and it is unclear whether additional resources were made available to the programme to stymie the risks. Subsequently, there was an increase from less than 15,000 cases in 1991 to more than 84,000 by 1994.

When an influx of construction workers entered Mauritius after a major typhoon, a resurgence of malaria occurred from zero local (since 1968) to 41 cases in 1975. Based on this experience, Mauritius anticipated future risk of imported malaria by implementing an extensive border screening programme, including follow up visits and screening for arriving at-risk groups and detected positive cases. Similar to Mauritius, an increase in intra-national and international movement in Cape Verde occurred as a result of improvements in ports and airports. The programme did not anticipate the impact of these projects. Bhutan’s malaria programme was rapidly moving toward elimination and was keenly aware of the high receptivity and vulnerability along the southern border with India. In addition, there were an estimated 35,000 documented workers in the country, the majority of which were employed in large-scale development projects in the interior and southern districts. Proactive case detection started in these development zones where migrants live and work. The programme also piloted Community Action Groups in the southern, receptive districts that have larger migrant flows from India. These groups enlisted community support in prevention and control of malaria.

The number of migrant workers originating from high transmission neighbouring countries propelled Malaysia’s Sabah State to begin collaborations with private sector plantations in the early 2000s to implement and surveillance of malaria to anticipate and avoid outbreaks.

The Philippines planned for malaria elimination by developing a certification process for subnational elimination in 2011, believed to be necessary because of the geography of the country, which is composed of many islands with different malaria potential.

The Namibia case-study did not provide specific examples of anticipation of threats.

Monitoring and evaluation

Monitoring and evaluation (M&E) includes monitoring programme outputs, such as whether intervention coverage and quality was achieved, and evaluation of impact. Most case-studies described evaluation of case data while some included vector control or surveillance data. Only two programmes emphasized the quality or coverage of interventions. An important part of M&E is analysis and swift feedback to the periphery, which should theoretically stimulate effective programme response, clearly M&E needs to be undertaken with a spirit of surveillance and response.

Only two case-studies highlighted the results of monitoring and showed that the programme did not achieve the coverage or quality targets. No case-studies included information on M&E of inputs and outputs. The Malaysia case-study gave the most comprehensive results of intervention monitoring, showing the difficulty in achieving coverage and timeliness of case investigation, diagnosis, vector control, and the intensive passenger screening programme.

For other countries, case reporting appeared to be the main tool for evaluation. Bhutan checked weekly case reports from the health facilities. The malaria programme followed up with health facilities for missing or incomplete reports, and if an increase in cases was reported, the respective health center was alerted. Namibia also reviewed weekly case reporting. In recent years, roll out of better diagnostic tools and coverage improved data quality and representation of the malaria burden. In addition, IRS quality was monitored after quality declined. A weakness cited in the Namibia case-study was the lack of data and limited feedback to the sub-national programmes.

Malaysia developed a web-based surveillance database in 2000 for M&E, which facilitated first the reporting of malaria cases, then included case investigation and vector control intervention data which could be monitored. Also in 2000, a separate online case notification system for health providers was introduced, where private and public health facilities rapidly reported all notifiable infectious diseases. The malaria programme regularly reviewed data from both systems and identified and contacted the hospitals, clinics, and private providers that failed to notify cases. The use of two parallel systems could have been cumbersome, but the report stated that the national and state programme officers used both databases to drive management decisions.

The monitoring and evaluation of malaria activities in Sri Lanka was coordinated by the Regional Malaria Officers (at district level) and by the AMC Directorate (national level). Sri Lanka built a web-based case information system in 2009, separate from the national health information system, to ensure reporting within 24 hours. The malaria programme planned to integrate the malaria reporting system into the national health information system after reaching elimination. In 2010, the malaria programme introduced a toll free hotline for private sector case reporting. In 2009, to increase data analysis, review and improve the feedback loop to the sub-national programme offices the malaria programme instituted case review meetings. These meetings were attended by Directorate and regional malaria programme officers, where details of each case and follow up measures were reviewed, and they provided an opportunity for feedback to the regional malaria officers, who then relayed information back to the districts. These meetings showed an openness to review, evaluation and change by both the national and regional levels.

There was a lack of information on the tools and processes used in Cape Verde and the Philippines for M&E.

For Turkey and Turkmenistan, resurgences demonstrated the weaknesses in monitoring and evaluation. In Turkmenistan, while transmission decreased when funding was available and activities were well-organized, delays in diagnosis, treatment and reporting fueled the outbreaks of 1998-99 and 2002-03. Case reporting did not flow to the central level in time for evaluation. Similarly, in Turkey, the delayed reporting to the provincial and national level contributed to the 1998-99 outbreak.

6.4.3 Enabling factors

There are many factors that enable or hinder progress towards elimination for a national malaria programme. Political commitment, funding, and human resources are three key factors that have a large influence on programme progress. These factors also determine the consistency of malaria programme implementation. Table 6.6 provides key learnings on enabling factors for malaria programmes.

Table 6.6 Key learnings on enabling factors of malaria elimination programmes

- Political commitment at the regional, national, provincial, district, and community levels took many forms and contributed to programme success.
- Sustained and long-term financial commitment to the malaria programme is a key to success.
- Consistency of malaria programmes depends on political commitment, human and financial resources, leadership of the malaria programme and operational capacity of the overall health system.

Political commitment

Depending on the country's level of decentralization and its health system structure, political commitment at the national or local level was a driving factor for malaria programme success. Political commitment took many forms, including enacting mandates or laws that support vector control activities and surveillance, ensuring adequate domestic funding and leadership and vision for elimination by national or local level leaders. Turkmenistan provides an example of the deleterious impact of waning political commitment when malaria incidence declines.

In Mauritius, there was a high degree of political commitment at the national level, evidenced by the consistent domestic financing of the programme. National policy was supportive to elimination, contributing to a high level of participation by residents in malaria control activities. There were penalties for non-compliance and health inspectors had legal power to inspect dwellings. Similarly in Malaysia, national policies and legislation were enacted to support elimination; for example, the malaria programme could engage in IRS and ITN distribution on private property and all foreign workers had to undergo screening for malaria before receiving a work permit. Sabah and Sarawak States had additional state-level ordinances to support malaria control activities.

Turkey's first elimination attempt was successful in part due to steady political commitment. Turkey experienced an epidemic in 1977, then signed the Tashkent Declaration in 2006, which outlined the strategy to achieve elimination in nine countries of the WHO EURO Region by 2015. With the Declaration, the malaria programme had the necessary political support to transition toward elimination in 2008.

The Bhutan malaria programme also had the support of the Ministry of Health -- outbreak reports reached the President's office. Namibia's elimination programme had the support of the Minister of Health, who was the former manager of the malaria programme and an advocate for regional elimination. In Cape Verde, an increase in malaria mortality (to eight deaths) in 2006 led to a greater level of attention of government leaders and the development of a new elimination goal of 2020.

National-level political commitment for elimination in Turkmenistan waned in the years leading up to the outbreak in Mary Province (2002-2003). In response, commitment was strengthened from 2004 onwards, as evidenced by the government financing dedicated to malaria in preparation for the certification process in 2010. The country then drew up a comprehensive national plan for prevention of reintroduction with support and commitment from the Ministry of Health and Medical Industry, Finance, and intersectoral cooperation.

In other case-studies, commitment at the local level was considered to be a driving factor for success. Malaysia's Sabah State developed and presented to the national programme a five year action plan for malaria control, which built the case for an increase in funding, human resources and development of subsector outpost offices in remote areas, in addition to scaling up of vector control, surveillance and community-based activities. The plan was successful and the state obtained funding from the national government for 100 additional positions. As a result, the proportion of cases investigated increased from 40% to 87% and malaria offices in remote localities were opened to provide microscopy, vector control, mass blood surveys, and health education.

Philippines also provided an example of the strength of commitment at the local level. Municipalities and communities participated and developed civic duty and pride through malaria programme activities, such as environmental clean-up events. The level of commitment and malaria experience of provincial managers had a large influence on the success of the programme. For example, Apayao and Laguna Provinces were highlighted in the case-study as having strong, knowledgeable, dedicated, well-liked and respected leaders, which drove action and success in their provinces.

Sri Lanka's malaria programme had commitment to malaria at both national and local levels. The malaria programme and Ministry of Health showed commitment through the maintenance of surveillance and vector control in the conflict zone. Commitment by the Ministry of Health continued even with very low malaria cases, evidenced by the maintenance of specialized malaria screening in health facilities and continuation of entomological surveillance.

Stable and predictable funding and human resources
Strong financial commitment has led to strong malaria control programmes. The case-studies showed three examples of resurgence primarily due to a reduction in human and financial resources for malaria elimination. Some countries relied purely on domestic financing, which caused some challenges in the past but overall appeared to increase the consistency of the programme when compared to countries that rely heavily on donor financing. Of interest is the specific question regarding how to maintain funding and skills of IRS spraymen and other staff on needed response activities when cases are very low or reach zero.

Three countries that have successfully eliminated malaria today had experienced resurgences after reaching or nearly reaching elimination in the past, in most part due to declines in funding or human resources. Reduced funding in Mauritius contributed to the resurgence in the 1970s. Inadequate financial and human resources led to Turkey's 1977 epidemic and again to the 1993-96 epidemic, where there were insufficient staff and health facilities in the area of a major development project, and insufficient malaria expertise at the provincial level. There was a decrease in staffing in receptive and vulnerable areas and delays in identification and reporting of cases. The lack of human and financial resources in Turkmenistan contributed to the 1998-99 outbreak as technical skills and declining staff were lost in the 1990s.

Post-resurgence, these countries built up their programmes in order to achieve elimination. Mauritius, where the government funded the malaria programme, spent over US $2 per capita on malaria in the period after the resurgence, despite zero indigenous transmission, in an effort to minimize the risk of resurgence. Per-capita expenditure during the first elimination attempt, before this latest resurgence, ranged from $6 to $3. A 100-person surveillance team and 100-person vector control team spent nearly 100% of time on malaria-related activities, a relatively large workforce in a context of zero indigenous cases. After the epidemic of 1977, Turkey increased its allocation to the malaria programme with a corresponding increase in the number of surveillance agents, laboratories, and microscopists. The country found that maintaining skilled personnel was essential to achieve elimination and prevent resurgence through rapid response to outbreaks.

After the 1998-99 outbreak in Turkmenistan, an initiative to build up the number of epidemiologists, lab technicians, and parasitologists began. Then, from 2005 to 2009, in preparation for the elimination goal, the programme doubled the number of malaria staff in parasitology, entomology, and laboratory diagnostics. By 2010, as mentioned previously, 11-20% of the government malaria budget was spent on training, an indicator of the Ministry's efforts to maintain quality interventions. The 2009-10 programme costs were covered mainly by the government.

Malaysia has had recent success in maintaining low transmission, partly attributable to the strength of the health system. Malaysia provided one of the few examples of a fully domestic-funded malaria programme in the elimination phase, which has led to a greater degree of consistency in funding and human resources when compared to other, donor-funded programmes.

Bhutan maintained a cadre of malaria technicians, even during years of declining malaria incidence. However, at the time of case-study publication, during elimination, these technicians were to be integrated into multi-purpose health workers. With this transition, there is a risk that commitment to malaria could wane. The case-study also reported on the importance of Global Fund grant funding (Rounds 4 and 7) for staff capacity building, development of community leadership and action, and malaria prevention commodities for hard to reach populations.
In the Philippines, provincial manager empowerment and ownership has increased consistency and increased funding by local governments. The case-study also noted the importance of Global Fund and other donor funding to maintain programme capacity.

Sri Lanka has had an adequate level of funding and resources over time, evidenced by consistent activities and the maintenance of specialized resources such as malaria-only diagnostic centers in health facilities. However, there was concern noted in the case-study about long-term, sustainable funding as the country reached its goal of zero malaria cases, in part because of the historical contributing factors to the 1987 epidemic, which included a shortage of Regional Malaria Officers. In addition, full time malaria programme staff decreased by 29% from 2004 to 2009, which reduced the number of public health field officers and IRS spraymen who were moved to other positions (e.g., clerks in medical institutions, drivers, assistants) and to other disease priorities (e.g., dengue) and were not easily released to work on malaria. These transfers of positions were likely due to the low number of cases where administrators did not consider it necessary to maintain a malaria control employee.

Cape Verde and Namibia provided examples of inconsistent funding and human resources. Cape Verde has received funding from the Global Fund and the Government of Spain. However, shortages in trained human resources for health and malaria control have continued to constrain the programme, evidenced by the single professional running the entire malaria programme at the national level.

Similarly, human resources and funding in Namibia were not considered adequate, even with the donor funding. There were vacant positions at every level, which led to a reactive rather than a proactive and planned approach. Staff turnover translated to an increased workload.

Consistency of programme implementation
Consistency of programme implementation over time depends on the level of political commitment, human and financial resources, and leadership of the malaria programme. It also depends on the operational capacity of the programme and the overall health system structure. Comparing the consistency, coverage and quality of interventions across the countries in the case-studies proved challenging, as these aspects of the programmes were not adequately documented. Changes in leadership, commitment and funding levels led to decreased consistency in some programmes. In three cases, programmes were consistent, leading to major reductions in malaria incidence, which precipitated a lower level of commitment and attention to the malaria programme and a lowering of quality and coverage of the programme. In

these cases, resurgence was around the corner, and instigated a rise in programme quality and coverage.

Turkey had success in its first elimination attempt in part due to the experienced, specialized network that carried out operations. Turkmenistan's outbreak of 1998-99 was partly due to a weakening of the surveillance system. Post-outbreak, the malaria programme ramped up training, surveillance and vector control activities, and ensured the supply of malaria control stocks well after the outbreak was contained.

Success in maintaining low cases in Malaysia, Bhutan and Sri Lanka was partly attributed in the case-studies to the strength of the health system and available infrastructure, including consistent availability of supplies, even in the conflict affected districts of Sri Lanka. However, in Malaysia, the high turnover of leadership in the disease control programme translated to a loss of institutional malaria knowledge and may have impacted the quality of implementation. Financial and political support in Mauritius allowed for consistency of implementation, even in the POR phase. For example, the passenger screening programme was maintained, which continued to draw human and financial resources during a period of zero local transmission. The Cape Verde and Namibia case-studies did not report a consistent level of malaria activity implementation. Both programmes had inadequate IRS coverage and quality at times. Restructuring of the programme and health system multiple times in the Philippines led to gaps in coverage of interventions, which affected programme performance. The case-study emphasized the role of the provincial manager in driving programme consistency through ownership, initiative and expertise.

6.5 Discussion

This paper reviewed nine case-studies examining malaria eliminating programmes and found that these programmes operated in highly diverse and challenging ecological, epidemiological, financial, political, and organizational contexts. However, despite this diversity, commonalities and learning points were identified that can help programme managers, policy makers and funders improve the functioning of malaria elimination programmes. Malaria programmes that were successful in eliminating malaria or greatly reducing malaria incidence had the following characteristics: clear lines of accountability and some degree of verticality in the programme; sustained political commitment and funding; a high degree of flexibility and adaptation to changing circumstances and tools; and multi-sector collaborations that facilitated response to threats of outbreak and resurgence.

The analysis of case-studies was limited by several factors. The original case-studies were based on retrospective data collection, and the quality of data varied across topics and themes across the case-studies. Data collection for the case-studies was broad, covering all malaria control strategies and activities and across many decades, meaning that detailed information on programme management strategies was not available for every case-study nor for every year covered in the data collection process. Furthermore, each final case-study report underwent a major review and editing process, which may have introduced errors, deleted concepts or changed perspectives. Due to financial and time constraints, a second round of in-country visits, key informant interviews and record review were not conducted for this cross-case analysis. Because of these limitations, relevant and helpful information or experience from national malaria programmes may not be represented in this analysis.

The comparative analysis distilled experience on the core components of programme management thought to be essential to accelerating towards global eradication. However, the analysis was unable to make specific recommendations on what did or did not lead to country progress towards elimination due to differences in the malaria programmes that exist beyond programme management. What was possible was to determine how malaria programmes handled challenges that were outside of their sphere of influence, partially under the influence of programme, or completely under the influence of the programme.

Malaria programmes faced several obstacles over which they had very little control. A major challenge was operating in a decentralized and integrated health system, where, in most cases, provincial or district health offices controlled malaria resources and implementation without defined, clear roles and responsibilities. The experience and knowledge base at the national programme was no longer utilized as it was in the past, and oftentimes the provincial offices did not have adequate training in the beginning of these transitions. Thus the subnational systems were not able to develop and implement tailored surveillance and response systems that are able to deal with the heterogeneity of transmission that occurs in elimination settings. In an integrated programme, diagnosis and treatment were provided by the general health services, generally by those without malaria expertise. For countries where decentralization or integration will be implemented, evidence suggests that integration must be gradual and well-planned. District officers must have adequate training and supervision and health workers need preparation and motivation to assist with malaria control. If possible, malaria programmes should advocate for sustaining some elements of verticality, such as multipurpose malaria-focused workers, to ensure sufficient attention to malaria. These positions can support non-specialists in the general health system and increase the quality of services [23].

Stronger malaria programmes have clear accountability by identifying who is responsible for achieving elimination, but this clarity can be challenging in an integrated and decentralized context. Experience from other disease eradication programmes found that designating a responsible central unit or an individual ensures leadership and coordination [24, 25]. National and state-level elimination plans are also helpful. A multi-sectoral task force, at the state or provincial level, ensures engagement from ministries and experts from other disciplines [24, 25]. Lastly, malaria programmes should seek to empower and increase authority of local level staff to ensure strong engagement and ownership of the malaria programme. Building management skills at the lower levels is one way to empower staff [26]. Implementing monthly case review meetings, convened by the national programme, where district level officers work together to interpret outcomes and identify lessons to improve daily practice, is a form of organizational learning and supportive supervision.

Malaria programmes have a degree of control over malaria programme capacity, supervision and motivation of workers. The productivity of workers and quality of services provided are critical to programme performance and both rely on staff capacity [26]. In most outbreaks or resurgences documented in the case-studies, contributing factors were inadequate staff, insufficient training and low-quality supervision. Experience from the malaria and smallpox eradication programmes has shown the necessity of adequate personnel that are well-trained, supervised, motivated, and capable of flexible action, evaluation and problem solving [4, 24]. Thus, training programmes must include both technical and operational components; on-the-job training, with emphasis on supervision and coordination [27]. Programmes can also consider shifting resources to continuing education and development, as large investments in training are often lost when there is no maintenance [26, 27]. Continuing education can also improve retention by incentivizing and motivating personnel. Supervision is also critical to programme quality, in particular for decentralized and integrated disease programmes and for those that depend on high quality surveillance activities that are field-based [21, 28]. Good supervision requires updated job descriptions with clear descriptions of roles and responsibilities [29]. While supervision usually takes the form of peripheral visits and checking information and supplies, monthly review meetings are another way to supervise and also facilitate peer-to-peer learning and exchange [24]. Problem solving and feedback, in particular supportive feedback, are important parts of supervision and build worker motivation [21].

The case-studies showed that malaria elimination workers are a diverse group, including paid and volunteer health workers, malaria programme and hospital staff, seasonal employees, and multi-sector partners. These personnel have different values and are motivated by different factors. For paid staff, a basic motivation package should be ensured, including reasonable level and timing of pay, working environments, potential for learning career advancement, and system capacities [26, 27]. Malaria programmes may be able to lobby their Ministry to ensure there is a basic package in place. Malaria programmes can also build forums for professionals to associate and learn from each other, and develop criteria for career advancement based on performance [17]. Perhaps most important, motivation is high when there is a clear goal and endpoint – malaria programmes can clarify their strategy and milestones, bringing the team along with them [24].

Malaria programmes have control over their efforts to improve the level of political commitment and funding, programme strategy and collaborations for malaria elimination. Political commitment at the global and national level is needed for elimination, as very well evidenced by experience from smallpox and polio eradication [24, 29]. Reliable financial commitment is also needed, from both domestic and international sources [2, 23]. Throughout the case-studies, the declaration of a national or subnational elimination goal often sparked and sustained political commitment and increased funding. In some cases, regional or global forums catalyzed support for a national elimination goal, through building awareness and friendly competition amongst countries.

The case-studies did not sufficiently document strategic plan development and their adjustments and adaptation, stratification and targeting of interventions. Targeting requires access to and analysis of real-time information with built-in feedback mechanism to the field where implementation decisions are made. Smallpox eradication experience shows that developing and using a minimum set of indicators will likely improve data use and utility in the field [24]. Targeted implementation and supervision is possible when good quality and real-time information is available [28].

There is a risk that elimination programmes are not flexible enough to adapt to conditions that continuously evolve as a country approaches zero local malaria cases. Instead of a ‘business as usual’ attitude, successful programmes in the case-studies constantly adapted new techniques and tools. Awareness and use of new tools is facilitated by having access to published and grey literature and to forums that bring together countries and partners to share experiences. In addition, strong programmes identified evolving threats to elimination, such as major development projects, and worked with other Ministries and the private sector to minimize the risks. In some cases, effective collaborations can entail contracting out services to private companies or NGOs.

6.6 Conclusion

Global malaria eradication will require well-managed malaria programmes providing high quality implementation of evidence-based strategies, founded upon strong surveillance and response strategies tailored to the subnational level transmission context, with adequate funding and human resources to sustain malaria elimination and prevention of reintroduction. A first step toward achieving this goal is to align national malaria operational plans, broken down to the subnational level, with the current operational and implementation guides, the GTS and the AIM. Roles and responsibilities at each level and across agencies must be clarified, including the multi-sectoral collaborators that will be integral to achieving elimination.

Management of malaria programmes may be enhanced by further training in supervision and management skills. The most technically savvy workers typically lack management experience [24]. An assessment of management practices and skills specific for malaria elimination may be helpful, in addition to workshops on organizational learning, problem solving, and financial management which can build morale in addition to skills [27, 30].

Based on evidence from other disease eradication programmes, there is a need to develop a minimum set of indicators that relate to elimination and eradication goals. Malaria programmes must have well-functioning real-time information systems and capacity for analysis with timely feedback to the field. Programme planning and targeting will not happen without access to good data and analysis.

Lastly, as seen from the gaps in information and evidence provided in the case-studies, it is clear that national operational plans must be accompanied by a portfolio of context-specific, programme management-related operational/implementation research that the programme will use to adapt and adjust strategies and interventions to achieve the highest level of impact.

There are still important gaps in evidence, such as how effective supervision is carried out, how workers are best motivated, and how to improve performance and retention of health workers in resource-constrained environments [21]. There are also evidence gaps on incentives and their use, in particular when working with community health workers [26]. Implementation of evidence-based, updated strategies along with building management and supervisory skills will move malaria programmes towards elimination and support steady progress towards global eradication.

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Chapter 7

DISCUSSION AND CONCLUSIONS

Over the last decade, the burden of malaria has shifted. In many countries malaria incidence has declined because of the implementation of new tools, increase in funding for malaria control, rising socio-economic status and changing environmental factors such as urbanization and deforestation that can reduce vector habitat. As a result of the decline in malaria transmission, a global goal of malaria eradication by 2040 has been proposed [1], bolstered by a new Global Technical Strategy for Malaria (GTS) [2] and an implementation and action framework, *Action and Investment to Defeat Malaria* (AIM) [3]. These pillars of action are supported by an update of the research and development agenda by MalERA that will support the goal of malaria eradication [4].

The GTS provides an underlying structure and cohesive strategy for elimination for global, regional and country level malaria programs, implementers, and researchers. There are three pillars of the global strategy: 1) universal access to malaria prevention, diagnosis and treatment; 2) an acceleration towards elimination and attainment of malaria-free status; and 3) Transformation of malaria surveillance into a core intervention [2]. These core efforts must be supported by the expansion of research and development of new tools, along with key enabling contextual factors, including political and financial commitment, regional collaborations, and capacity development of malaria programs in programme management and operational research [2]. By 2030, the GTS predicts that at least 35 countries, of those that had malaria transmission in 2015, will have eliminated malaria. Countries are now adapting the strategic framework of the GTS, shaping it to their context and revising their elimination goals and strategies.

New country and regional elimination goals, and the overarching global goal of eradication and strategy laid out in the GTS, are evidence of a major shift in global discourse over the last decade. The first attempt to eradicate malaria, the Global Malaria Eradication Programme (GMEP) (1955-1970), was discontinued after 1969 when eradication was no longer considered attainable with available funding, capacity and tools [5]. Although eradication as a long-term goal continued, it was no longer considered achievable for most countries and most of them reverted to strategies for malaria control [5]. Beginning in the early 1990s, however, action was taken to update strategies and secure more funding for malaria control, in response to increasing malaria-related morbidity and mortality in large part due to increasing drug resistance to chloroquine, the first-line malaria treatment at the time. Major gains in malaria control followed as initiatives and new tools brought new life to malaria control, including the formation of the Roll Back Malaria Partnership, the foundation of the Global Fund to Fight AIDS, Tuberculosis and Malaria and the President's Malaria Initiative, and the scale up of ITNs [3, 6]. By 2007, many countries were making steady progress in controlling malaria and this positive message was further elevated by Bill and Melinda Gates' landmark announcement in October 2007 of the Bill & Melinda Gates Foundation goal to eradicate malaria. Malaria partners, including the World Health Organization, began to support efforts and strategies for elimination and for an eventual eradication goal.

As a result, in the late 2000s, elimination and eradication goals were again being considered by the global malaria community. However, after years of focus on malaria control, there was little awareness of how countries were eliminating the disease. Countries considering or embarking on elimination did not have access to the vast experience of other national elimination programmes. To fill this gap, efforts were made to share country experiences, successful strategies, challenges, and the tools and resources required to reach the last mile. The UCSF Global Health Group – WHO Global Malaria Programme Eliminating Case-Study Series was developed to share these experiences with elimination, and identify the key success factors on the road to elimination.

The purpose of this thesis was to conduct a historical analysis of countries that have pursued elimination, both successfully and unsuccessfully, and learn about and describe the most important strategies and approaches to achieving and maintaining malaria elimination. The first task was to describe in detail two malaria elimination programmes – Sri Lanka and Bhutan. Through a case-study format, the analysis identified programmatic strengths and weaknesses, and highlighted decisions, activities and strategies that contributed to the reduction in malaria burden in both countries. The second task of this research was to analyze a series of case-studies on malaria programmes that have been successful in reducing malaria burden or achieving elimination. Three themes were identified for the cross case-study analysis that were considered important for elimination and for which it was thought that the case-studies had enough information to analyze: programme management, surveillance and response, and vector control. The WHO GMP led the analysis on surveillance and response, thus it is not included as part of this thesis. The cross case-study analysis included as raw material the case-study reports of the UCSF Global Health Group-WHO Global Malaria Programme Eliminating Case-Study Series. UCSF Global Health Group led the development of the Bhutan, Sri Lanka, Malaysia, Mauritius and the Philippines case-studies. The WHO Global Malaria Programme completed five case-studies (Cape Verde, La Reunion, Tunisia, Turkmenistan and Turkey), of which four were complete by the time of the cross case-study analysis and thus were included in this thesis.

The first aim of the study was to identify the key programmatic strengths and major challenges for elimination of two malaria programmes, Bhutan and Sri Lanka. The GTS strategies of provision of access to prevention, diagnosis and treatment and the transformation of surveillance into a core intervention are both supported by evidence from these country case-studies. The Bhutan and Sri Lanka malaria programmes found success in reducing malaria transmission by ensuring access to malaria prevention: IRS and LLINs contributed to declines in malaria transmission in both countries; LLINs were particularly useful in remote areas of Bhutan and in conflict-affected areas of Sri Lanka, both places where IRS was logistically challenging. Expanded access to health services and diagnosis was a key factor – Bhutan increased diagnostic services across the country, while Sri Lanka maintained a strong passive case detection system and increased active surveillance activities. A key strategy in the GTS is surveillance as a core intervention. Both countries implemented case-based surveillance with timely reporting as a key component of their malaria programmes [2]. The GTS also argues for programme innovation in implementation, which was seen in both countries. Evidence-based decision-making and policy changes, such as the introduction of ACTs in Bhutan and insecticide rotation strategies in Sri Lanka, were believed to have supported declines in incidence. There were some major differences in their programmes, however, as they adapted interventions and their combinations to the local context [2]. Sri Lanka had a very strong entomological surveillance programme, continued from the early days of the malaria programme and this emphasis on capacity of the entomology programme was considered a key strength. Sri Lanka also had the particular challenge of maintaining services and surveillance in conflict areas. Bhutan experienced major economic development, thought to have fueled the decline in malaria incidence but also contributed to its struggles to manage imported infections.

The second aim of the study was to identify the key programme management and vector control strategies that contributed to declines in malaria or the achievement of elimination, through two thematic cross case-study analyses. As was found with the individual case-studies, the results of the cross case-studies align closely with a key pillar of the GTS: the need for programmes to transform malaria surveillance into a core intervention at the national and sub-national levels. For this transformation, malaria surveillance data must be collected regularly through well-organized reporting systems. This data should be used to track current disease and entomological trends and programme performance. The vector control cross case-study found that strong malaria programmes spent a great deal of resources and time on generating robust data. They collected information on vector control intervention coverage and entomological surveillance data, and the strongest programmes used these data and analyses to adapt vector control strategies and interventions to local and rapidly changing conditions. The programme management analysis found that strong programmes tracked programme operations through analysis of coverage data and epidemiologic trends. In addition to the importance of surveillance and response, the programme management analysis results aligned closely with the GTS' priority supporting element for elimination - a strong enabling environment, bolstered by sufficient capacity for effective programme management and strong political and financial commitment. The analysis on program management found that high quality programme operations is a key indicator of success. Quality is enhanced by structured, supportive supervision and is affected by the level of motivation of malaria workers. An element of verticality in the programme was a characteristic of several successful programmes, in addition to having sufficient resources, capacity, and political commitment for elimination in the country.

The methods used in the case-study analyses had positive and negative aspects. The UCSF Global Health Group – WHO Global Malaria Programme Eliminating Case-Study Series, which included the case-studies on Bhutan and Sri Lanka, used a mixed method approach to do retrospective data collection. Quantitative and qualitative data collection was conducted, including desk review of documents, in-country document review, quantitative data extraction in-country, and key informant interviews using a semi-structured interview format. The data collection methods were not standardized across all case-studies, although a Minimum Essential Dataset was developed to build a platform from which all national malaria programmes could be compared and, at the same time, to develop a set of indicators that could be used as a framework for elimination evaluation efforts nationally, regionally and globally (Appendix 5). Analysis was conducted using data triangulation, which consists of a review, synthesis and interpretation of data from multiple sources.

There were some positive aspects of these methods. First, the topics and references were broad, which ensured that information on every aspect of the malaria programme was collected and enabled a comprehensive view of the programme. The lack of standardization across case-study data collection procedures meant that researchers had the flexibility to focus on interesting aspects of a country programme. The key informant interviews involved every level of programme staff so that the perspectives of field teams to national programme managers on what strategies worked and what did not were captured. Another benefit of the methods was that data collection and analysis were conducted in close collaboration with malaria programme personnel, which facilitated a deeper understanding of the programme. Programme staff were exposed to mixed method research and in many cases programmes increased their research capacity. As a result of this collaboration with malaria programmes, case-studies were used in the development of National Strategic Plans, grant applications to the Global Fund, and documentation in support of WHO elimination certification.

The methods also led to some weaknesses. Because of the broad scope of topics, in some programmatic areas there was a shallow level of detail available in the case-studies, for example in management aspects such as health worker motivation packages and incentivization. Most reports covered large spans of time, so were not focused in on specific details. Additionally, the retrospective nature of the studies, broad focus, and reliance on qualitative data made it impossible to infer causality between interventions and declines in malaria incidence. Furthermore, because the case-study methodology was based on a close collaboration with malaria programmes, with case-study researchers working daily with malaria programme management and personnel, researchers had to use diplomacy and negotiate inclusion of results that were not always wholly positive about programme efforts. At times this led to reports or publications that avoided an honest critical assessment of a programme.

The Minimum Essential Dataset was not completed in a robust way, mainly because malaria programmes did not have data for each indicator for each year included in data collection. The composition and priorities of research teams also led to inconsistency in completing the datasets. Since the development of the dataset there has been more discussion on the key indicators for malaria elimination, at the different levels of evaluation (national, regional, and global), through regional forums and WHO technical forums.

Methods for the cross case-study analyses were based on development of a conceptual framework, developed by reviewing relevant documents and manuals, and its review by malaria elimination researchers and experts. This framework was then used to collect data through a thorough review of each case-study report and extraction of qualitative data for each concept. A workshop facilitated the re-review of conceptual frameworks in light of the available data and a review of the thematic matrices of data to ensure that all data and experiences were represented in the analysis.

The cross case-study methods had many positive aspects. Malaria elimination experts and researchers were engaged in the development of the conceptual framework and workshop. Their participation resulted in lively discussions on malaria elimination, such as malaria programme achievements and the most critical programmatic elements, and the key conceptual components of vector control and programme management. The cross case-study analyses also served as a way to more critically assess malaria programme efforts, which was a challenge in the individual case-studies. Negative assessments were diffused and less threatening when presented in aggregate.

There were also weaknesses of these methods. The cross case-study analyses relied upon the data available in the case-study series, which in turn was based on retrospective data collection, with a high degree of variation in depth and quality of data across studies. This variation and at times weakness was a result of the breadth of data collection, and also due to the different research teams that led the work (except for Bhutan and Sri Lanka, which were led by this author). The researchers often had different time constraints or priority interests. In some cases, programmes simply had limited information on a particular topic or missing data. The cross case-study research would have benefited from in-country record review and key informant interviews focused specifically on programme management and vector control, which was not conducted because of financial and time constraints. Because of these limitations, relevant information or experience from malaria programmes may not have been represented.

In conclusion, this body of work shows that there is already a great deal that is known about malaria elimination in different contexts, what works and what does not. Importantly, this work identified the key programmatic elements and enabling factors that are required for successful elimination, and the improvements that are needed. The priorities found in this body of work align closely with the overarching technical strategy set forward in the GTS, in particular the role of the surveillance system as a core intervention of all malaria elimination programmes [2]. When there is a robust surveillance programme in place, which generates and analyzes parasitological and entomological data, the programme is able to use data and results of analysis to develop evidence-based strategies. Backstopping these efforts is strong leadership of the programme, an enduring high level of motivation in health workers, and the political and financial commitment for elimination. All of these attributes, characteristics and organization were found in the most successful malaria elimination case-studies.

Surveillance was a core programme intervention in the strongest eliminating countries. Malaria programmes conducted case-based surveillance and were able to identify, follow up, classify and respond to each malaria case, whether indigenous or imported. This effort becomes feasible in a low transmission context and requires a well-maintained health system that provides broad and timely access to diagnosis and treatment. The GTS emphasizes the role of strong national health systems that support case-based surveillance in the drive to elimination. Limited availability of human resources, in particular in the periphery, can negatively impact the strength of the health system and capacity for this type of surveillance. When malaria cases decline, capacity can be further reduced as other diseases with higher morbidity and mortality are prioritized. These are challenges for which malaria programmes must plan.

A second but equally important emphasis found in the case-studies of malaria programmes was the entomological surveillance programme. Programmes that maintained capacity and technical know-how in the entomology and vector control units were able to consistently generate entomological surveillance data. Strong programmes staff up entomology units with a skilled cadre and build in supervision of field activities. However, a weakness found across the case-study series was the measurement of vector control intervention quality, coverage, and impact on transmission. More information is needed on how prevention tools are targeted and accessed by populations that need them, and whether they are actually used as proscribed. This information is key to understanding intervention effectiveness at the local level. Many tools are highly efficacious in controlled settings but much less effective in community settings because of problems with targeting, access, compliance or adherence. Data can be generated and analyzed to answer these questions. Data should also ensure that the populations most at risk of malaria are targeted with the interventions that will protect them. This is a key message in the GTS.

The case-studies highlighted the need for data-driven strategies, which in turn require quality data from routine parasitological and entomological surveillance, and measurement of intervention quality and coverage. Evidence-based strategies can only be crafted if there are trustworthy, locally-driven data on the populations most at risk and their location, vector breeding, and effectiveness of the prevention tools. While many programmes had an abundance of data and spent a great deal of resources on data collection, it was unclear how data were used in analysis, feedback and development of response packages to be implemented by field teams. Specifically there was a gap in the description of how programmes can link entomological and epidemiological data to develop strategies and identify optimal intervention tools, coverage targets, and timing.

High functioning malaria programmes drew from surveillance data and used the evidence to craft and adapt prevention and response strategies as needed to local and constantly changing conditions. This adaptation requires a flexibility of the programme to change course when needed. Programme flexibility in turn relies upon adequate human resource capacity and technical skills. Human resources and capacity is required not only at the central level, but also at the sub-national level, where most operations occur. Capacity in the periphery is typically weakest thus requires attention to ensure that flexibility is built in to the entire programme.

Strategy, planning, and ensuring a high degree of flexibility in a programme are set in motion by programme leadership. Strong malaria programmes had strong leaders. Malaria programmes with an element of verticality in their structure appeared to have a higher leadership capacity and greater accountability for achieving elimination goals. Leadership influenced many aspects of the programme, from ability to adapt new strategies to motivation of staff. Worker motivation is an important component of elimination programmes, but results of this analysis shows that this area has the most room for improvement. Examples of supportive supervision and high quality training, such as continuing education packages, were few. More attention must be paid to incentivization of malaria workers. These findings are backed by the GTS, which highlights the need for technical expertise and human resource capacity to be maintained in elimination programmes.

The GTS also accentuates political and financial commitment as one of the major supporting elements for malaria elimination. The strongest malaria programmes in the case-study analyses had strong political commitment and adequate funding. Most programmes had access to Global Fund malaria grants, which supported activities and commodity procurement. Access to resources contributed to declines in incidence. However many programmes do not or will not have access to these funding levels as they progress towards zero local cases and are expected to transition to domestic financing.

These analyses point to two areas of recommendation. First, there are several areas of research that, if investigated now, would provide much-needed guidance for elimination programmes. The major priority is to build the evidence and understanding of different approaches to surveillance and response that have been effective in lowering malaria transmission. Surveillance systems have to be adapted to the local context, health system, capacity and funding. Programmes would benefit from information on and evidence from different approaches, such as the role of active case detection in malaria elimination. Research on how programmes have built their surveillance systems would also be useful, if it includes information on the financial and capacity requirements, and measurement of its impact in driving down malaria transmission. Related to this investigation is the need for a detailed analysis of how malaria programmes currently link and analyse epidemiological and entomological surveillance data. Showing how this type of analysis could be used to formulate programme strategy, specifically responses to cases, would provide an example for programmes that are not yet doing so. A second area for exploration is methods for improving programme quality, communication and supervision. The application of organizational development to the field of malaria elimination may have interesting results. Implementation of such exercises must be accompanied by clear measurement of impact on programme operations and its cost-effectiveness.

There are a few points of action that can be taken forward now, given the current evidence on what successful malaria elimination programmes have done. The first priority is for malaria programmes to build out surveillance and response systems to be a core intervention. These systems must track and respond to each case, and for that must include a streamlined rapid reporting infrastructure that ensures timely reporting. Further research on surveillance approaches, as described above, will assist programmes in identifying the best methods, however it is known now that case-based surveillance must be implemented to reach elimination. Capacity to conduct entomological surveillance is also crucial to strengthening overall surveillance systems. Programmes will need to plan for the additional resources, capacity and skills required to build and run such a surveillance system and find dependable funding before implementation. Increases in staff technical skills and capacity along with better reporting structures are likely to benefit other disease programmes, such as dengue and zika control, in the years to come.

In addition to surveillance and response systems, elimination also requires good management, which in turn relies on quality data on what is happening on the ground. A minimum set of highly useful indicators will measure quality of operations in a consistent way across malaria programmes. There has already been some work on this area, most recently by the WHO Surveillance, Monitoring and Evaluation Technical Working Group with contributions by the UCSF Global Health Group, which can be further utilized by programmes, donors and implementing partners to track progress towards malaria elimination, measure operations quality and identify areas for improvement.

Lastly, action can be taken now to develop methods and strategies for supportive supervision, opportunities for continuing education and other ways to motivate workers who are busy doing the hard work of malaria prevention and control. The malaria community would benefit by working with management and organizational development experts to understand how to build programmes that serve and motivate its workers. Funding will of course be required to take this forward.

The case-studies on malaria elimination programmes are stories of inspiration, of national ambition and drive. From the central to local levels, communities and malaria programme personnel are driving to achieve a major goal – elimination of a long-standing and persistent parasite from within their borders. There are many challenges, as seen and described in this body of work. Gains made thus far in malaria control and elimination are fragile, and will only last as long as programmes remain vigilant and capable of rapid and robust response to every case. Importation of malaria is constant threat. Resistance to anti-malaria therapy and insecticides for vector control further threaten progress. Through sharing the lessons learned in these eliminating case-studies, it is hoped that other countries will be able to translate the technical strategies of the GTS and those implemented by successful malaria programmes into their national and subnational elimination strategies. For the eradication goal, the response and drive must come from the global level with buy in and hard work at the national and subnational levels. Continued investment in research and development is also required. With determination, adequate resources and drive at the national and regional levels, and an increase in the impressive technical and management skills already available, eventual global eradication is possible.

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APPENDIX

Appendix 1. A Desk Review of Literature on Malaria Control and Elimination in Sri Lanka
The desk review identified the following publications and grey documents relating to Sri Lanka and malaria control and elimination.

<u>Publications on malaria control and elimination in Sri Lanka (112)</u>

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Appendix 2: A Literature Review on Malaria Control and Elimination in Bhutan
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Appendix 3. Program Management Conceptual Framework/Data Collection Matrix (original)(.xls)

		BHUTAN	CAPE VERDE	MALAYSIA	MAURITIUS	NAMIBIA	PHILIPPINES	SRI LANKA	TURKEY	TURKMENISTAN
Malaria Programme Status										
Vertical vs. horizontal chain of command										
	Centralized/Decentralized health									
	Vertical vs. integrated malaria program									
Effective generic management practices										
	Supply of materials, supply chain									
	Leadership of interventions									
	Sustained commitment									
	Control of resources									
	Management information									
	Incentives and accountability									
	Supervision skills and procedures (monitoring)									
	Capacity building/skills training/maintenance									
Additional information										
Application of managerial practi										
	Organization development									
	Organizational learning									
	Action learning									
	Action research									
	Behavior change									
	Social marketing methods									
	Resourcing managerial practices									
Implications for research										

Appendix 4. Bibliography of references for the development of the conceptual framework on program management

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Appendix 5. Minimum Essential Dataset

Malaria Elimination Case Study - Minimum Essential Data (MED)					
Notes:	This data should be collected for priority years included in the case study.				
	Indicator	**Quantitative Variable**	**WHO WMR Database (Pre-Elimination and Elimination Phase)**	**Qualitative Variable**	**Remarks**
Background information					
	Year				
	Country				
	Name of programme				
	Name of person(s) assisting				
	Function				
	Email				
	Phone				
	Fax				
EPIDEMIOLOGY					
Population at Risk					
	PAR	Number of people living within active foci (new, active, and endemic)	X	Vector control interventions used in given foci	
		Number of people living within residual active foci	X	Vector control interventions used in given foci	
		Number of people living in malaria-free areas	X	Vector control interventions used in given foci	
		Total population	X	Vector control interventions used in given foci	
Vectors					

	Vectors	Five primary vectors in order of importance	X		
Reported Cases and Deaths					
	All Cases	Suspected relapse		Algorithm for identification ; Seasonality of malaria	If information not available, write N/A in Remarks
		Suspected congenital		Algorithm for identification	
		Symptomatic cases			
		Asymptomatic cases			
	Microscopy - tested	Slides examined	X		
		Positive	X		
		P. falciparum	X		
		P. vivax	X		
		Other species	X		
		Mixed			
	RDT - tested	Slides examined			
		Positive			
		P. falciparum			
		P. vivax			
		Other species			
		Mixed			
	Indigenous Cases	Slides examined	X		
		Positive	X	Algorithm for identification	
		P. falciparum	X		
		P. vivax	X		
		Other species	X		
		Mixed	X		
	Introduced Cases	Slides examined	X		
		Positive	X	Algorithm for identification	
		P. falciparum	X		
		P. vivax	X		
		Other species	X		
		Mixed	X		
	Induced cases	Slides examined			
		Positive		Algorithm for identification	

		By species			
	Imported Cases	Slides examined	X		
		Positive	X	Algorithm for identification	
		P. falciparum	X		
		P. vivax	X		
		Other species	X		
		Mixed	X		
	Deaths	Indigenous	X	Algorithm for identification	
		Imported		Algorithm for identification	
		Not classified/other	X	Algorithm for identification	
	Classification of foci	Number new potencial foci		Primary vector control interventions used in given foci	
		Number new active foci		Primary vector control interventions used in given foci	
		Number endemic foci		Primary vector control interventions used in given foci	
		Number residual active foci		Primary vector control interventions used in given foci	
		Number residual non-active foci		Primary vector control interventions used in given foci	
		Number cleared up foci		Primary vector control interventions used in given foci	
Reported Cases and Deaths by Surveillance Type					

PASSIVE CASE DETECTION				
	Total persons examined			
	Positive			
	P. falciparum			
	P. vivax			
	Mixed			
	Other species			
ACTIVE CASE DETECTION				
Proactive Active Case Detection (ACD)	Total persons examined	X	Strategy for proactive case detection: when implemented	
	Positive	X		
	P. falciparum			
	P. vivax			
	Mixed			
	Other species			
Case Investigation	% of cases investigated		Case investigation strategy (measures, rationale); Algorithm for identifying case as imported.	
	% of all cases that are investigated within 24/48 hours			
Reactive Case Detection - epidemiological investigation	Number persons examined		Strategy for reactive case detection	
	Positive			
PREVALENCE				
Prevalence Surveys	Date and type of last survey			
	Estimated parasite prevalence from last survey			
G6PD deficiency	Estimated prevalence of G6PD deficiency		Policy of G6PD testing before treatment; Prevalence surveys	

				undertaken; Impact of surveys or literature on program policy	
	OTHER				
	PCR and Serological Surveillance	PCR prevalence (Plasmodium DNA prevalence)		Use of PCR in program	
		Serological prevalence		Use of serology in program	
HEALTH SYSTEM					
Completeness of Reporting in Previous Year					
		Type of facility included in outpatient reports in previous year: Government/Mission/Private/Other	X		
		Frequency of outpatient reporting: Daily/Weekly/Monthly/Quarterly/Annually	X		
		Number of reports expected per year from each health facility	X		
		Total number of health facilities expected to report each month	X		
		Total number of reports actually received the previous year	X		
INTERVENTIONS					
National Policies					
	IRS	Implemented in current year: Yes/No; Year started; Focus on specific foci or region?	X	Primary vector control intervention? Insecticide-resistance monitoring undertaken?	
	ITN/LLIN	Implemented in current year: Yes/No; Year started; Focus on specific foci or region?	X	Distribution strategy (universal, targeted, at risk groups, foci	

				stratification) ; Free or subsidized	
	Larval control	Implemented in current year: Yes/No; Year started; Focus on specific foci or region?		Use of larviciding in vector control of foci	
	Diagnosis	Implemented in current year: Yes/No; Year started; Focus on specific foci or region?	X	Public sector fee for diagnosis, national scheme for external QA,	
	Treatment	Implemented in current year: Yes/No; Year started; Focus on specific foci or region?	X	First-line treatment (PF, PV, complicated/ severe); Treatment in private sector	
	Surveillance	Implemented in current year: Yes/No; Year started; Focus on specific foci or region?	X	Strategies on reactive case investigation, foci case investigation, case reporting from public/private sectors, resistance monitoring	
Interventions					
	IRS	Number of foci sprayed			
		Number of households targeted for IRS			
		Number of households sprayed			
		Population targeted for IRS	X		
		Estimated number of people protected by IRS	X		
	Larval control	Number of breeding sites identified		Type of larviciding used - specify	
		Number of breeding sites targeted for larval control			

		Number of breeding sites treated			
		Estimated population protected through larval control measures			
	ITN/LLIN	Number of ITNs/LLINs distributed	X		
		Number of people targeted for ITNs/LLINs			
		Estimated number of people protected by ITNs/LLINs			
	Treatment	Number first-line treatment courses distributed for *P. falciparum*	X		
		Number of radical treatment courses distributed for *P.vivax*			
		Number of reported primaquine adverse events			
FINANCING/ COSTING					
Malaria Financing by Year (USD)					
	Government contribution	Total government budget	X		
		Health budget	X		
		Malaria budget	X		
		Malaria expenditure	X		
	External contributions	GFATM (Including all PRs)	X		
		WHO	X		
		Other (bilaterals, NGOs, foundations, etc.)	X		
Expenditure Breakdown 2010 (USD)					
	Human Resources & Technical Assistance		X		
	Training		X		
	ITNs		X		
	Insecticides & spraying materials		X		
	Diagnostics		X		
	Anti-malarial medicines		X		
	Procurement & supply management		X		

	Infrastructure & equipment		X		
	Communication & advocacy		X		
	Monitoring & Evaluation		X		
	Planning, administration, overheads		X		
	Other		X		
	Total		X		
	Amounts are budgets/disbursements/expenditure?		X		
MANAGEMENT/HUMAN RESOURCES		Quantitative Variable			
Quality Control					
	Supervision protocol	For ITN/LLIN distribution		Content of protocol and way to measure adherence	
		For IRS			
		For entomological surveillance			
	Supervisory visits	Number of visits to personnel within three months			
	External Quality Assurance (EQA)	Number of laboratories providing diagnosis for malaria			
		Number of laboratories participating in EQA scheme for malaria			
Human Resources					
	Malaria Program Work Force	Number of total posts			
		Number of posts occupied			
		Training/retraining within three years			