COMMUNITY-BASED SURVEILLANCE AND CONTROL OF MALARIA VECTORS IN URBAN DAR ES SALAAM, TANZANIA

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Thesis submitted in accordance with the requirements of the University of Liverpool for the degree of Doctor of Philosophy

March 2012

ABSTRACT

Recent increase in political and funding commitments to malaria control have resulted in rapid scale up of indoor residual spraying (IRS) and long-lasting insecticidal nets (LLINs) as priority vector control interventions. Despite this increasing coverage and consequent substantial reductions of malaria burden, residual malaria transmission by outdoor-biting mosquitoes in particular, necessitates complimentary vector control strategies such as larval source management. More sensitive and scalable entomological surveillance tools are required to monitor the resultant lower transmission levels that persist across much of the tropics. The Urban Malaria Control Program (UMCP) in Dar es Salaam, Tanzania, implements a large-scale community-based (CB) larviciding programme with the aim of demonstrating operational feasibility of integrating larval control into routine municipal services, while utilizing community-owned resource personnel (CORPs) for its implementation.

The goal of this study was to a better understanding of community participation in larval-stage vector surveillance and control, and to develop a practical, safe and affordable prototype for routine programmatic adult mosquito surveillance. Qualitative methods involving administering a set of unstructured interviews to CORPs were used to investigate their performance and demographic characteristics, their perceptions and reasons for participating in the UMCP. Ethnographic and historical resources were used to examine how ‘participation in’ and ‘responsibility for’ larval control is inter-articulated through scientific protocols, development practices, and the specific political history of Tanzania. Cross-sectional surveys were later used to assess the effectiveness of operational, community-based larval habitat surveillance systems within the UMCP by estimating the respective detection coverage and sensitivity levels by CORPs. Additionally, an intensive and extensive CB system for routine, longitudinal, programmatic surveillance of mosquitoes using the Ifakara Tent Trap (ITT) was developed and evaluated in comparison with quality assurance (QA) surveys using either ITT or human landing catches (HLC) and with malaria parasite prevalence from the cross-sectional surveys.

Overall, CORPs’ individual detection coverage and sensitivity levels were poor, influenced by his/her unfamiliarity with the area, habitat type, fencing and inclusion within larviciding roll out. These indicators were particularly low among CORPs recruited through programme management staff, compared to those recruited by local government officials or health committees, and among staff living outside their areas of responsibility. The CORPs perceived their role to be professional rather than voluntary, with participation being a *de facto* form of employment. In spite of all challenges, the central coordination role played by the city council, coupled with catalytic donor funding and technical support from expert research partners, enabled institutionalization of strengthened management and planning and improved community mobilization. Capacity to exploit national and international funding systems was enhanced and a sustainable implementation program was ultimately established with funding from the Ministry of Health and Social Welfare, overseen by the National Malaria Control Programme and implemented by the City and Municipal Councils. Management of this program is currently supported by a spatially extensive and temporally intensive community-based longitudinal adult mosquito vector surveillance system with predictive power for parasite infection risk.

DECLARATION

None of the contents in this thesis has been previously submitted for a degree in this or any other university. Where use has been made of the work of others, it is duly acknowledge in the text. Chapters 2, 3 and 4 have been submitted for publication or published already as papers in peer-reviewed journals in slightly different format from that presented here. The contributions of each of the various collaborators involved in each chapter are listed below:

Chapter 1: Introduction and literature review

Prosper Pius Chaki (PPC), wrote the entire chapter. Dr. Gerry F Killeen (GFK) edited the chapter.

Chapter 2: The challenges of achieving high coverage of larval-stage mosquito surveillance

PPC took the lead in designing, implementing the study, data analysis and in writing of the chapter. NJG supported the design and implementation of the study, BS and AH participated in the implementation of various aspects of the larval surveillance and supervision of data management systems for the program. UF and GFK designed and implemented the larviciding system. UF and MT contributed substantially to drafting of the chapter. GFK supervised all aspects of the study design, implementation, data analysis and drafting of the chapter. All the authors have read and approved the final chapter.

Chapter 3: Community-Owned Resource Persons for malaria vector control: enabling factors and challenges in an operational programme in Dar es Salaam, Tanzania

PPC led the design and implemention of the study, data analysis and wrote the chapter. AK and SD supported the design and implementation of the study. UF, KK and GFK designed and implemented the larviciding system. GFK supervised all aspects of the study design, implementation, data analysis and drafting of the chapter. All authors have read and approved the final chapter.

Chapter 4: An affordable community-based malaria vector surveillance system that reflects human infection risk

PPC took the lead in designing and implementing the study, data analysis and in writing of the chapter. YM, AM and DM participated in the implementation of various aspects of the adult mosquito and household parasitology surveys as well as data management. NJG, ADM, ZJM, TLR and SK supported the design and implementation of the various study aspects including data management. GFK was involved in designing the larviciding system that these vector monitoring systems are intended to support. YZ and NFL supported the PDA programming, data collection and management. SD contributed substantially to producing the maps and edditing of the chapter. GFK supervised all aspects of the study design, implementation, data analysis and drafting of the chapter.

Chapter 5: Landscape of responsibility: Evolving of Roles and Responsibilities for communities and institutions in a larval control programme for malaria prevention in urban Dar es Salaam, Tanzania

PPC took the lead in designing, implementing the study, data analysis and in writing of the chapter. AK and GFK supported through the process of developing the idea and drafting of the chapter.

Chapter 6: General discussion and conclusions

PPC wrote and GFK edited this chapter

Signed…………………………..... (Candidate)

Date…........../…………/…………

DEDICATION

I dedicate this work to my lovely wife Doreen and daughter Julia for constantly being supportive to me and enduring the long times of my absence

TABLE OF CONTENTS

DECLARATION ii

DEDICATION v

TABLE OF CONTENTS vi

ACKNOWLEDGEMENTS xi

LIST OF TABLES xiii

LIST OF FIGURES xiv

LIST OF ABBREVIATION xvi

CHAPTER ONE 1

1.1 An Introduction to Malaria 1

1.1.1 Malaria biology and the Plasmodium life-cycle 2

1.1.2 Life cycle in the human host 3

1.1.3 Sporogonic development of the parasite in the mosquito vector 5

1.2 Epidemiology, ecology and distribution of malaria 8

1.2.1 Clinical manifestations of malaria and associated genetic disorders 8

1.2.2 Distribution of malaria risk and burden 9

1.2.3 Biological and environmental determinants of malaria transmission 11

1.3 Past, present and future of malaria control 16

1.3.1 Malaria control through environmental management in the first half of 20th Century 17

1.3.2 Switching to adulticdes 20

1.3.3 The rise and fall of the Global Malaria Eradication Program 21

1.3.4 Revival of vector control for malaria prevention 25

1.3.5 Scaling up ITNs/LLINs and IRS in the modern era 26

1.3.6 Going beyond LLINs and IRS: Community based integrated vector management 28

1.4. Opportunities for community-based larval source management 29

1.4.1 Integrated vector management 31

1.4.2 Environmental management 32

1.4.3 Larviciding ... 33
1.4.4 Monitoring and evaluation of malaria vector control programmes ... 35
1.5 Opportunities for developing community-based larval source management systems in Urban Dar es Salaam, Tanzania ... 38
1.5.1 Cities as ideal settings for development, evaluation and scale up of larval source management ... 39
1.5.2 A brief history of larval source management in urban Dar es Salaam, Tanzania ... 41
1.5.3 The contemporary Urban Malaria Control Programme (UMCP) ... 44
1.6 Goal and Objectives ... 48
1.7 Specific objectives ... 48
CHAPTER TWO ... 49
2.0 Abstract ... 50
2.1 Background ... 52
2.2 Methodology ... 55
2.2.1 Study area ... 55
2.2.2 Routine programmatic larval surveillance by community based personnel ... 56
2.2.3 Qualitative preliminary assessment of community-based larval surveillance ... 58
2.2.4 Quantitative cross-sectional evaluation of community-based larval surveillance ... 59
2.2.5 Statistical analyses ... 60
2.3 Results ... 61
2.3.1 Habitat characteristics found during cross-sectional evaluation ... 61
2.3.2 CORPs' detection of aquatic habitats ... 66
2.3.3 CORPs' detection of aquatic stage mosquitoes ... 71
2.4 Discussion ... 76
2.5 Conclusion ... 78
CHAPTER THREE ... 79
3.0 Abstract ... 80
3.1 Background ... 82
3.2 Methodology ... 87
3.2.1 Study Area ... 87

3.2.2 Routine programmatic larval surveillance by community-based personnel 88
3.2.3 Qualitative preliminary assessment of community-based larval surveillance 89
3.2.4 Quantitative cross-sectional evaluation of community-based larval surveillance 90
3.2.5 Data Analysis 91
3.3 Findings 92
3.3.1 CORPs' demographic characteristics 92
3.3.2 Contextual determinants of detection coverage identified through the guided walks 94
3.3.3 Determinants of aquatic habitat detection coverage 97
3.3.4 Determinants of larval-stage mosquito detection sensitivity 99
3.4 Discussion 102
3.5 Conclusion 104
CHAPTER FOUR 106
4.0 Abstract 107
4.1 Background 109
4.2 Methodology 114
4.2.1 Study Area 114
4.2.2 The Dar es Salaam UMCP 115
4.2.3 Routine programmatic adult mosquito surveillance by community-based personnel 118
4.2.4 Randomized quality assurance entomological surveys 121
4.2.5 Cross sectional epidemiological survey 123
4.2.6 Data Analysis 124
4.2.7 Ethical consideration and informed consent 126
4.3 Results 127
4.3.1 Relative sensitivity of alternative survey systems using tent traps 129
4.3.2 Relationship between mean mosquito densities and malaria infection prevalence 135
4.4 Discussion 143
4.5 Conclusions 146
CHAPTER FIVE 148

5.0 Abstract 149
5.1 Background 150
5.2 Methodology 156
5.3 Larval Control Logic 157
5.4 Ward Councils 166
5.5 Origins and evolution of a community-based malaria vector control programme for modern Dar es Salaam 172
5.5 Institutional roles and responsibilities 172
5.6 The essential strategic role of community participants in larval source management 180
5.7 Community engagement and mobilization tactics 183
5.8 Scaling responsibilities: the complementary roles of communities and institutes 186
5.9 The community-local government interface 189
5.10 The researcher-implementer interface 190
5.11 Progress and Prospects 192

CHAPTER SIX 196

Preamble: 197

Summary and indepth review of the major outcomes of the research 199
6.1 Synopsis of the main findings implications for monitoring and evaluation of malaria control programmes 199
6.2 Community-based monitoring of mosquito larvae as a management tool for measuring coverage of larviciding 204
6.3 The CORPs' experience of public health delivery: lessons learned for future malaria control programs 208
6.4 Surveillance and early management platforms for effective and sustainable larviciding work 210
6.5 The role of independent evaluation and routine monitoring of adult mosquito population and the future of vector control 215
6.6 Beyond mosquito surveillance: Remaining delivery, surveillance and management challenges for LSM programmes 219

6.7 Summary recommendations and implications of the research findings for malaria control policy in Africa 227

REFERENCES 232

APPENDICES 290

CORPs' questionnaire 291

ACKNOWLEDGEMENTS

This work would not have been successful completed without the contribution of many people. I wish to thank my primary supervisor Dr. Gerry Killeen, for introducing me to this field of malaria research and control strategies and for his cordial way of advising me. His scientific mentorship, commitment, friendship and the many good discussions and laughs, with a lot of trust in me have kept me going. Thank you for your unfailing readiness to guide me and for your wise comments during the planning stages, data analysis and writing. Special thanks to Prof. Hilary Ranson and Dr. Louise Kelly-Hope, my secondary supervisors, for their constant professional support and personal encouragement that helped to maintain my personal motivation constantly at threshold level. Dr. David Malone and Dr. Greg Devine assessed the progress and provided valuable inputs to my work. *Thanks and I highly appreciate*. I would like to thank Prof. Steve Lindsay and Dr. Ulrike Fillinger for their constructive comments on some chapters of this work and for hosting me while I was registered at Durham University before transferring to Liverpool. I am grateful to Dr. Anne Kelly for her constructive and friendly support towards the completion of chapter sections. Thank you for the many stimulating discussions and good insights to the concepts of medical anthropology. I would like to extend my appreciation to Dr Chris Drakeley and Dr Jennifer Stephenson from the London School for their valuable discussions which contributed to the drafting and accomplishing of one of the chapters.

I sincerely thank my colleagues at Ifakara Health Institute: Dr. Nico Govella, Bernadette Huho, Yeromin Mlacha, Jane Macha, August Joachim, Victoria

Mwakalinga, Daniel Msellemu, Dr. Silas Majambere and Dr. Stefan Dongus for collaboration, friendship, and with numerous encouraging discussions.

I wish to thank Khadija Kannady (the UMCP manager) for her support, friendship and always having an open ear to my questions and for all the exciting, challenging discussions we have had. I would also like to thank all the UMCP staff, Byson Shoo, George William, Adinan Ally, Jonson Ndaro, Hemed Abdullah, James Msami, all the municipal inspectors and ward supervisors for their cooperation and facilitating this work during my field visits. I would also like to express my appreciation to the regional, municipal and local government leaders, as well as the residents of Dar es Salaam for their tremendous support and cooperation throughout the study. Special thanks are due to all the mosquito catchers for their enormous commitment to this work.

I am grateful to the Wellcome Trust (Research Career Development Fellowship 076806 awarded to Dr. Gerry F. Killeen), from the Bill & Melinda Gates Foundation (Malaria Transmission Consortium project grant 45114, coordinated by Professor Frank Collins & Dr. Neil Lobo at Notre Dame University) for funding this study, as well as the Ifakara Health Institute for core salary support when it was needed most.

LIST OF TABLES

Table 2.3.1	Occupancy of different mosquito habitat categories and types by all stages of *Anopheles* and *Culicine* larvae……………….	65
Table 2.3.2	Detection efficiency of different aquatic mosquito larval habitat types and categories by CORPs………………………	68
Table 2.3.3	Factors associated with habitat detection coverage by CORPs	72
Table 2.3.4	Detection sensitivity of larval stages in different aquatic mosquito larval habitat types and categories by CORPs	74
Table 2.3.5	Factors associated with Anopheline and Culicine detection sensitivity in wet habitats reported by CORPs………………	76
Table 2.3.6	Impact of larviciding on late stage *Anopheles* larvae occupancy…………………………………………………..	77
Table 3.3.1	Assorted responses from the interviewees illustrating the main contextual factors influencing their routine performance	97
Table 3.3.2	Factors associated with mosquito larval habitat detection coverage……………………………………………………	100
Table 3.3.3	Factors associated with Anopheline and Culicine detection sensitivity by individual CORPs..	102
Table 4.3.1	Relative sampling sensitivity of community based (CB) and quality assurance (QA) surveys of mosquitoes with ITT, compared with QA surveys by human landing catch (HLC), as estimated by generalized linear models (GLM) …………...	132
Table 4.3.2	Crude estimates of the costs for each surveillance method per night of trapping and per *Anopheles gambiae s.l.* caught over the selected period outlined in figure 4.3.2 when all three surveillance systems were simultaneous in operation. All costs are presented in Tanzanian Shillings (Tsh) at a mean 2010 exchange rate of 1408.02 per US$……………………..	134
Table 4.3.3	*Anopheles gambiae* mean catch per night as risk indicator for malaria parasite prevalence among children and teenagers (<20 years of age) as determined by fitting separate logistic regression models to data from each of the three survey methods. See table 4.3.2 for details of sample sizes for each entomological survey data set. Note that for all three models location ($P \leq 0.001$) and date ($P \leq 0.001$) included in the models were also highly significant random effects…………………..	142
Table 4.3.4:	Comparison of the surveillance system described in this paper with some published large scale and longitudinal entomological surveys for monitoring interventions against malaria vectors. ………………………………………………	143

LIST OF FIGURES

Figure 1.1.1	The life cycle of the malaria parasites…………………………..	7
Figure 1.2.1	Global malaria risk distribution 2009…………………………..	15
Figure 1.3	Reporting structure of the UMC………………………………..	46
Figure 1.5.1	Map of Dar es Salaam, showing the location of the respective wards with different colours depicting the various subsequent phasing of the larviciding intervention………………………….	48
Figure 2.2.1	Community-based implementation of the UMCP roles………..	59
Figure 2.3.1	Proportions of wet habitats and late-stage *Anopheles*-positive habitats found by CORPs within fenced and unfenced plots…..	64
Figure 2.3.2	Aerial photos for planned and unplanned settlements in urban Dar es Salaam alongside ground-based photos of common features for each. ……………………………………………	70
Figure 4.2.1	Map of Dar es Salaam showing the wards and respective locations where community-based adult mosquito surveillance was conducted.……………………………………………….	118
Figure 4.3.2	The monthly mean *Anopheles gambiae* (**A**) and Culicine (**B**) densities from the three independent alternative surveys routine Community-based surveys using Ifakara Tent Trap (CB-ITT), Quality assurance surveys based on both human landing catch (QA-HLC) and tent trap (QA-ITT). ……………………………	129
Figure 4.3.3	Correlation of the alternative ITT-C based survey results with quality assurance surveys based on human landing catch (HLC) gold standard reference method for sampling *An. gambiae s.l.*...	131
Figure 4.3.4	Density-dependence of alternative ITT-based survey methods relative to the HLC-based QA surveys for sampling *Anopheles gambiae s.l.* and *Culex* spp.…………………………………….	135
Figure 4.3.5	The frequency distributions of the person trap nights and mosquito densities across a range of survey locations by the three surveillance systems………………………………………	137
Figure 4.3.6	The relationship between age-specific malaria parasite prevalence distribution and mean vector density (*An.gambiae* and *An.funestus* combined) with different vector density intensity strata as determined by the three mosquito surveillance systems....…………………………………………………...	139
Figure 4.3.7	Correlation between mean catches of *Anopheles gambiae s.l.* per location and proportion of malaria infection prevalence per cluster……………………………………………….……….	141
Figure 5.5.1	The origin, developmental and subsequent reforms of UMCP responsibilities among stakeholders over the six years................	175
Figure 5.5.2	The scaling up and subsequent distribution of UMCP responsibilities among different stakeholders at the various administrative levels as well as spatial and temporal scales.........	188
Figure 6.1.1	Schematic presentation of the different chapters and sections, various indicators and determinants studied in this thesis with	

	regard to the vector and malaria disease life cycle......................	197
Figure 6.2	Application of microbial larvicide granules (*Bacillus thuringiensis var israeliensis*) by the UMCP CORP..................	221
Figure 6.3	Traces of *Bacillus thuringiensis var israeliensis* granules in a breeding habitat sprayed by UMCP CORP…………………….	222

LIST OF ABBREVIATION

ACT	Artemisinin Combination Therapy
BMGF	Bill&Melinda Gates Foundation
Bs	*Bacillus sphaericus*
Bti	*Bacillus thuringiensis var israelinsis*
CB	Community Based
CI	confidence interval
CORP	Community Owned Resource Persons
CMOH	City Medical Office of Health
DDT	Dichlorodiphenyltrichloroethane
DURHAM	Durham University
EIR	Entomological Innoculation Rate
ELISA	Enzyme-linked immune-sorbent assay
EM	Environmental Management
GEE	Generalized estimating equation
GFFATM	Global Fund Fight Against AIDS, Tuberculosis and Malaria
GIS	Global Geographical Information Systems
GMAP	Global Malaria Action Plan
GMEP	Global Malaria Eradication Programme
GLM	Generalized linear model
GLMM	Generalized linear mixed model
HARVARD	Harvard University
HLC	Human landing catch
IHI	Ifakara Health Institute
IMC	Ilala Municipal Council
IMMOH	Ilala Municipal Medical Office of Health
IRS	Indoor residual spraying
ITN	Insecticide-treated net
ITT	Ifakara tent trap
ITT-B	Ifakara tent trap design B
ITT-C	Ifakara tent trap design C
IVM	Integrated Vector Management
KMMOH	Kinondoni Municipal Medical Office of Health
LLIN	Long lasting insecticide-treated net
LSM	Larval Source Management
M&E	Monitoring and Evaluation
MoHSW	Ministry of Health and Social Welfare
NA	Not applicable
NIMR	National Institute for Medical Research
NMCP	National Malaria Control Program
PCR	Polymerase chain reaction
PMI	United States President’s Malaria Initiative

QA	Quaality Assured
RBM	Roll Back Malaria
RR	Relative rate
RS	Remotely Sensed imagery
RTI	Research Triangle Institute
SPSS	Statistical package for social science (software program for statistical analyses)
STI	Swiss Tropical Institute
TCU	Tenc-ell Unit
TMMOH	Temeke Municipal Medical Office of Health
UMCP	Urban Malaria Control Program
USAID	United States Agency for International Development
VBC	Valent Biosciencies Corporation
WHO	World Health Organization
WT	Wellcome Trust

CHAPTER ONE

INTRODUCTION AND LITERATURE REVIEW

1.1 An Introduction to Malaria

In sub-Saharan Africa, malaria is a major cause of morbidity and mortality especially, among children less than five years of age and pregnant women (WHO 2010). Malaria situations are very diverse as a result of local heterogeneities in the determinants of malaria transmission dynamics and the great variety of their local combinations (Gething *et al.* 2010, Hay *et al.* 2009, Marsh and Snow 1997). These include environmental (Bates *et al.* 2004b, Greenwood and Mutabingwa 2002, Hay *et al.* 2005, Kiswewski *et al.* 2004), biological (Hay *et al.* 2004, Killeen *et al.* 2001, Kiswewski *et al.* 2004), social, cultural (Bates *et al.* 2004a) and economic (Sachs and Malaney 2002) factors. Recently renewed interest in malaria prevention and treatment has necessitated the development of innovative new approaches and more effective implementation of affordable interventions that are already available (Alonso *et al.* 2011a, Breman *et al.* 2007, Feachem *et al.* 2010, Raghavendra *et al.* 2011, Sabot *et al.* 2010, Steketee and Campbell 2010, Takken and Knols 2009, Tanner and Savigny 2008, van Eijk *et al.* 2011). Despite the long history of systematic malaria control efforts, malaria remains a threat in over 100 countries, the majority of which are in South East Asia and the tropical and sub-tropical regions of Africa (WHO 2010). Ongoing macro-scale global malaria control efforts rely entirely upon the national and local level implementation and management of proven interventions, based on relevant monitoring and evaluation data, so that epidemiologic impact is optimised and verified.

1.1.1 Malaria biology and the Plasmodium life-cycle

Human malaria is an infectious disease caused by protozoan blood parasites of the genus *Plasmodium* that is transmitted by female mosquitoes of the genus *Anopheles.* It is predominantly distributed in the tropical and subtropical parts of the world where high temperatures facilitate rapid development of the sporogonic parasite stages that infect mosquitoes (Feachem *et al.* 2010, Guerra *et al.* 2010, Hay *et al.* 2009, Snow *et al.* 2005). There are five *Plasmodium* species known to regularly infect humans, namely *Plasmodium falciparum*, *Plasmodium vivax*, *Plasmodium malariae*, *Plasmodium ovale* and *Plasmodium knowlesi* (Carter and Mendis 2002, Greenwood *et al.* 2008, Marquardt *et al.* 2000, Mueller *et al.* 2009, Roberts and Janovy Jr 2000, Singh *et al.* 2004, Warrell *et al.* 2002). The former is the most common species in sub-Saharan Africa and also causes the most severe forms of the disease (Gillies and DeMeillon 1968, Marquardt *et al.* 2000, Service 1977), contributing more than two-thirds of the annual malaria disease burden worldwide (Snow *et al.* 2005, WHO 2009). *Plasmodium falciparum* malaria is readily recognized by its ability to bind to the endothelium of the blood vessels during the blood stages of the infection, thereby sequestering in organs such as the brain, kidneys and spleen. *Plasmodium knowlesi* has historically been regarded as a malaria parasite of long-tailed macaque monkeys but has recently been reported to commonly infect humans in some parts of Asia (Singh *et al.* 2004). The development patterns of the members of the genus *Plasmodium* includes both sexual and asexual phases involving two different hosts; a vertebrate host (usually a human being in the case of medically relevant species) where the schizogony and gamogony processes occur, and a mosquito as the definitive host where complete maturation of the gametes, fertilization and sporogony take place.

1.1.2 Life cycle in the human host

Human host infection with a *Plasmodium* parasite begins with either a bite from an infective female *Anopheles* mosquito that inoculates sporozoites-stage parasites from the mosquito's salivary glands into the individual during a blood meal (Warrell *et al.* 2002) (Figure 1.1) or, far less commonly, through blood transfusion. All female *Anopheles* mosquitoes require blood meals to produce viable eggs (Beier 1998). When the mosquito takes a blood meal, the long proboscis probes into the host's skin, searching for a capillary while at the same time injecting salivary fluid from the glands in the thorax to inhibit blood clotting. For infective mosquitoes, the salivary fluid carries along motile sporozoite-stage parasites with it into the skin tissue or even directly into the bloodstream. After invading the human host, they are carried through the body by the blood stream for approximately thirty minutes until they reach the liver. These motile sporozoites then each penetrate a liver cell (hepatocycte), initiating the liver-stage-infection where they develop into exo-erythrocytic schizonts. After 6 to 15 days, these rupture, releasing merozoites which invade red blood cells and multiply asexually (exo-erythrocytic development) through a process referred to as schizogony (Carter and Mendis 2002, Roberts and Janovy Jr 2000) (Figure 1.1).

Once inside a red blood cell, the merozoite rounds up to form early trophozoites characterized by ring shape, measuring between 2 to 4 µm in diameter with a clear vacuole and single nucleus. Progressively, the growing rings appear irregular in shape and the vacuole becomes less definite and pink, showing stippling forms in the cytoplasm of the erythrocytes. The trophozoites ingest haemoglobin by pinocytosis. The undigested portions of the haemoglobin, known as hemozoin, remain as tiny black granules that sometimes appear to stain green because of their refractive property. Nuclear replication without cytoplasmic division follows through an amitotic splitting of the nuclear material, a stage commonly referred to as presegmenter. Complete merozoite formation (segmenter stage) occurs when each nucleus is wrapped in an envelope of cytoplasm and plasma membrane. The asexual blood stage in vertebrate host is normally completed every 48 hours for *P.falciparum,* and *P.vivax,* 50 hours for *P.ovale,* or 72 hours for *P.malariae*) after the merozoite has entered the red blood cell, at which point about 12 to 20 new merozoites have formed and the host erythrocyte ruptures so that they can invade new ones (Paul *et al.* 2003). At the point breakdown of the parasitized red blood cell, the hemozoin, erythrocyte cell membranes, and metabolic by-products of the parasite are released into the bloodstream of the host. The synchronized development of these erythrocytic stages, resulting in near-simultaneous rupturing of a large number of merozoite-infected red blood cells and massive release of these toxic materials into the plasma, is associated with the characteristic periodic and dramatic onset of clinical symptoms arising from the asexual blood stages. The resulting clinical manifestation of malaria includes periodic fevers, muscle ache, abdominal discomfort, loss of appetite, lassitude and lethargy (Carter and Mendis 2002, Greenwood *et al.* 2008, Marquardt *et al.* 2000). These symptoms apply to all the malaria species but are particularly likely to be severe for *P.falciparum*.

At the end of the schizogony process, the red blood cell bursts, releasing a dozen or more new merozoites which begin this cycle of multiplication all over again (Paul *et al.* 2003). As the infection progresses, the asexual blood stages of the parasite not only grow rapidly, their development tends to become increasingly synchronized with time, so that a blood sample taken at any one time typically reveals the vast majority of parasites in the same stage of schizogony (Carter and Mendis 2002, Roberts and Janovy Jr 2000). In the cases of *P. ovale* and *P. vivax*, some sporozoite innoculations may result in an infection that is dormant for months, years or even decades in the liver as hypnozoites (Beier 1998, Roberts and Janovy Jr 2000, Warrell *et al.* 2002). This cryptic, inactive stage eventually re-activates and initiates the typical blood-stage infection by releasing merozoites. The hypnozoite stage is responsible for the late relapses of the infection that make these two parasite species particularly difficult to treat and eliminate (Greenwood *et al.* 2008, Marquardt *et al.* 2000, Molineaux *et al.* 1988). Completion of blood stages involves the differentiation of some merozoites into non-pathogenic male and female gametocytes after erythrocyte invasion. These sexual forms that are ingested by a mosquito when taking a blood meal, leading to a sexual crossing and development process called sporogony (Beier 1998, Roberts and Janovy Jr 2000, Warrell *et al.* 2002).

1.1.3 Sporogonic development of the parasite in the mosquito vector

Once inside the mosquito gut, each gametocyte transforms into haploid female macrogametes or male microgametes. Influenced by reduced temperatures and changes in blood pH, the nucleus within the microgametes begins to divide as soon as the blood reaches the midgut of the mosquito (Beier 1998). This process takes about 15 minutes with the formation of 6 to 8 motile, threadlike, single-nucleus microgametes from each male gametocyte. On the other hand, the nucleus within the macrogametes moves to the periphery of the female gamete, slightly protruding at the surface to form a cone shape (Beier 1998). The microgametes swim toward the macrogametes and penetrate them at the point of nucleus protrusion, at which stage fertilization occurs (Beier 1998). These ultimately fuse together to form a zygote, thus completing the sexual phase. In about one hour, the formed zygote transforms into a motile stage of the parasite, known as an ookinete, which burrows into the midgut wall by squeezing between the gut epithelial cells of the mosquito. Within a few days, the ookinete develops into an oocyst that grows between the basal lamina and epithelium of the mid-gut wall. The oocyst undergoes sporogony through repeated nuclear divisions to produce thousands of sporozoite-stage parasites that forcefully rupture the oocyst to migrate to the mosquito's hemocoel, a few of which subsequently enter and invade the salivary glands (Beier 1998, Roberts and Janovy Jr 2000). At least 8 days after ingesting the gametocytes, the mosquito becomes infectious to humans and the cycle is resumed with the injection of the sporozoites to another human host by the infected female *Anopheles* mosquito during blood feeding (Roberts and Janovy Jr 2000).

The duration of this parasite development phase within the mosquito is highly influenced by the external temperature (Beier 1998). The parasite incubation period becomes much longer at suboptimal temperatures, thus limiting the development and distribution of *Plasmodium* species to warm climates and seasons. The importance of temperature in limiting *Plasmodium* propagation is well illustrated by comparing the ranges of different parasite species: the sporogonic development of *P.vivax* within mosquitoes can occur at much lower environmental temperatures than that needed for *P.falciparum* and this accounts for the more widespread prevalence of the former in temperate regions outside of the tropics and subtropics (Abeku *et al.* 2004, Guerra *et al.* 2010, Mendis *et al.* 2001).

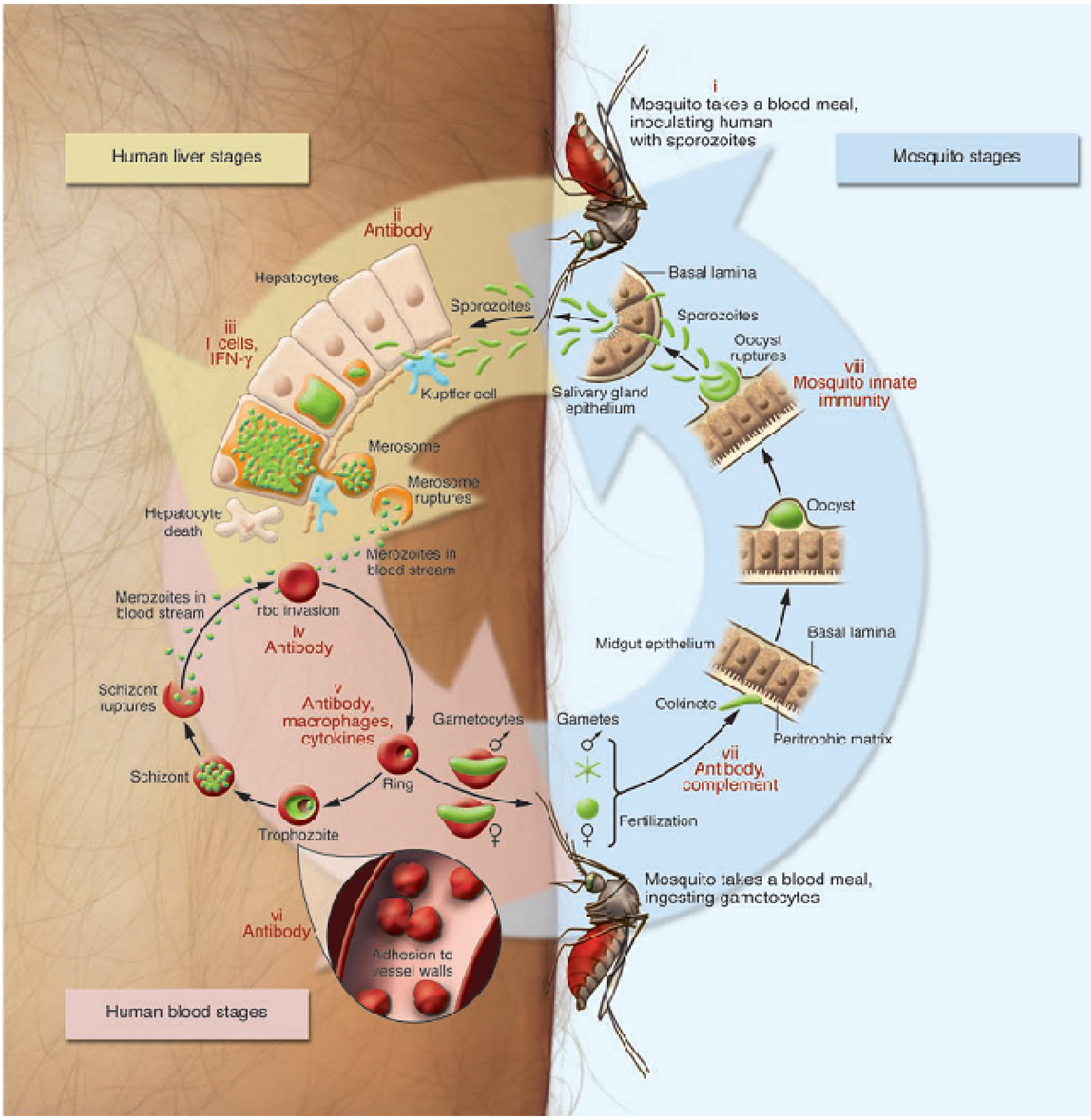

Figure 1.1: The life cycle of the malaria parasites. Source Greenwood et al (2008)

1.2 Epidemiology, ecology and distribution of malaria

1.2.1 Clinical manifestations of malaria and associated genetic disorders

Malaria infection can manifest itself in a variety of clinical forms, largely depending on local transmission intensity. All the five malaria parasites display more or less similar clinical manifestations associated specifically with the asexual blood stages, including periodic paroxysm, chills and rigors, sweating, body aches, headache, nausea and general body malaise. However, these are withal common sysmptoms of several other infectious diseases, making malaria difficult to diagnose based on clinical symptoms alone. Splenomegaly is also a common feature of untreated malaria infections and repeated exposure to infection. The most severe forms of the disease are usually associated specifically with *P. falciparum* infection, often leading to dysfunction of vital organs such as the kidneys, spleen and brain. However, over the long history of man's relationship with malaria, human beings have undergone several genomic adaptations that help to counteract disease manifestation and even infection. These include the lack of the Duffy blood group antigen among most Africans and their diaspora. This protein is expressed on the surface of erythrocytes and is a necessary receptor for *P.vivax* and *P.knowlesi* merozoites to invade red blood cells. The predominance of Duffy-negative alleles has limited the prevalence of this species among indigenous Africans populations (Carter and Mendis 2002, Mason *et al.* 1977, Mendis *et al.* 2001, Miller *et al.* 1976, Zimmerman *et al.* 1999). Others include sickle cell haemoglobin, thalassemias, ovalocytosis and glucose-6-phosphate dehydrogenase deficiency, all of which confer some type of protection against malaria by either reducing the infection risk or averting severe symptoms and death (Carter and Mendis 2002). It should be noted that many of these genetic polymorphisms are themselves associated with disease conditions and can only persist at such high frequencies because of the strong selection pressure arising from the protection they confer against malaria (Carter and Mendis 2002).

1.2.2 Distribution of malaria risk and burden

One hundred and thirty years after Laveran's ground breaking discovery of malaria parasites in human blood, and Ronald Ross demonstrating that malaria parasites are transmitted by female *Anopheles* mosquitoes, endemic malaria still covers a large part of the world, putting nearly 3.3 billion people at risk (WHO 2010). Worldwide, about 243 million cases of human malaria are reported annually, with about 85% of the cases occurring in Sub-Saharan Africa (WHO 2010). Young children under the age of five years are the most affected group where transmission is stable and endemic, with other high-risk groups including pregnant women as well as refugees and visitors from non-endemic areas because all these population groups have little acquired immunity (Guyatt and Snow 2004, Hay *et al.* 2005, WHO 2010). It is estimated that before recent scale up of malaria control measures, about 863,000 people die from malaria worldwide every year, with almost 80% of deaths occurring among young children in sub-Saharan Africa (WHO 2010). The distributions of malaria risks and burden are overwhelmingly dependent on the geographical variations in human susceptibility to species of malaria parasites and upon the transmission capacity of mosquito vectors and climate (Hay *et al.* 2004, Martens *et al.* 1995, McMichael *et al.* 2006, Zimmerman 1992).

Repeated and frequent exposure to malaria infection is consistently associated with the gradual development of protective antimalarial immunity (Marsh and Snow 1997, Snow *et al.* 1999, Trape and Rogier 1996). There are basically two forms of the acquired protective clinical immunity: the first protects against the life threatening forms of the disease among older children and adults whereas the second modifies the clinical manifestations of infection (Carter and Mendis 2002, Marsh and Snow 1997). If malaria cases in a given locality occur mainly among young children, then the area most probably experiences moderate to high transmission intensity so that older children and adults typically carry low density, sub-patent infections and also suffer less severe forms of disease due to the high levels of acquired immunity. Such immunity will reduce the incidence of clinical malaria but not infection rate (Molineaux *et al.* 2002, Smith *et al.* 2006). On the other hand, if cases are equally distributed across all age groups, such susceptibility of the entire population to infection suggests a lack of protective immunity due to infrequent exposure. Based on such variations in infection rates and age-prevalence patterns, malaria transmission is often categorized as being stable and endemic, or unstable and epidemic. Stable endemic conditions are experienced when a population is exposed to a consistently high rate of malaria infection associated with the development of strong protective immunity early in life. On the other hand, unstable and epidemic conditions, with the latter being an extreme case of the former, have low infection rates, resulting in little or no immunity in any age groups and ubiquitous vulnerability to severe malaria (Fontaine *et al.* 1961, Mouchet *et al.* 1998, Trape and Rogier 1996). Globally, a whole spectrum of transmission intensities and endemicity patterns is represented across the tropics, with the most intense transmission occurring Sub Saharan Africa and the pacific where the biological and environmental determinants of transmission are most permissive.

1.2.3 Biological and environmental determinants of malaria transmission

Only mosquitoes of the genus *Anopheles* are capable of transmitting human malaria. Currently, about 462 *Anopheles* species have been described globally, 70 of which are known to be potential vectors of human malaria (Gillies and DeMeillon 1968, Hay *et al.* 2010, Kiswewski *et al.* 2004, Service and Townson 2002, Warrell *et al.* 2002). The *An. gambiae* complex (Coetzee *et al.* 2000, Paterson 1964) is a group of seven morphologically indistinguishable species showing pronounced ecological and behaviour diversity *Anopheles gambiae* Giles, *Anopheles arabiensis* Patton, *Anopheles quadriannulatus A and B* Theobald, *Anopheles bwambae*, *Anopheles melas* Theobald and *Anopheles merus* Donitz (Gillies and DeMeillon 1968, Gillies and Coetzee 1987, Mosha and Petrarca 1983, Muirhead-Thomson 1948, Muirhead-Thomson 1951, Service 1993b, Temu *et al.* 1998, White 1974, White 1985). The *An. funestus* group is comprised of nine members including *Anopheles funestus*, *Anopheles vaneedeni* Gillies & Coetzee, *Anopheles rivulorum* Leeson, *Anopheles parensis* Gillies, *Anopheles aruni* Sobti, *Anopheles confusus* Evans & Leeson, *Anopheles fuscivenosus* Leeson, *Anopheles leesoni Evans*, and *Anopheles brucei* Service (Gillies and Coetzee 1987, Hargreaves *et al.* 2000, Kamau *et al.* 2002, Koekemoer *et al.* 2002). However, only two species from this group, *An. funestus* and *An.rivulorum* have been implicated as vectors to malaria parasites (Mendis *et al.* 2000, Wilkes *et al.* 1996). The most important vector species occurring in sub-Saharan Africa include *Anopheles gambiae* Giles, *Anopheles arabiensis* Patton, *Anopheles funetus* Giles, *Anopheles melas* Theobald and *Anopheles merus* Donitz (Bruce-Chwatt 1966b, Coluzzi 1984, Gillies and DeMeillon 1968). *Anopheles gambiae s.s.* and *Anopheles. arabiensis* are the most widely spread efficient vectors of malaria and filariasis in Africa with females of the former species showing high degree of anthropophily (Gillies and DeMeillon 1968, White 1974). These primary African vectors typically breed in relatively clean water bodies such as temporary small ponds, seepages and puddles as well as in more permanent habitats such as marshes and the swamps, whereas *An.merus* and *An. melas* have adapted to brackish coastal habitats in east and west Africa respectively (Gillies and DeMeillon 1968, Gillies and Coetzee 1987, Holstein 1954). While fresh water *Anopheles gambiae* complex members prefer breeding in temporary sunlit clean aquatic habitats, *A.funestus* larvae proliferates in shaded vegetated fringes of more permanent or semi-permanent swamps, lakes, ponds, water holes or river beds. Consequently, the latter is far more focally distributed but less dependent on rains and often persists at high density during the dry seasons while the densities of the former becomes scarce. This larval habitat preference among the primary malaria vectors of Africa contributes to the decline of malaria transmission with progressive urbanization and pollution. While members of the *Anopheles gambiae* complex are the most common and ubiquitous malaria vectors in Africa, and dominate transmission in most localities, *Anopheles funestus* exhibits a more focal distribution, often dominating transmission where it is abundant (Fontenille *et al.* 1997, Gillies and DeMeillon 1968, Gillies and Coetzee 1987). The contrasting seasonal variations of population size for *An. gambiae sensu lato* and *An. funestus* helps explain why malaria transmission is so stable in sub-Saharan Africa: Whereas the density of *An. gambiae s.l.* typically peaks during or soon after the rainy season (Gillies and DeMeillon 1968), *An. funestus* , typically persists and may peak during the dry season (Gillies and DeMeillon 1968, Gillies and Coetzee 1987, Holstein 1954, Kiswewski *et al.* 2004, Mbogo *et al.* 2003, Minakawa *et al.* 2002), thus maintaining transmission throughout the year. The ability of mosquitoes to transmit malaria varies due to environmental and climatic conditions, as well as their abundance, host preference, feeding frequency as well as survival and ability to incubate malaria parasites

(Beier 1998, Bruce-Chwatt 1966a, Coluzzi 1984, Ferguson and Read 2002, Lindsay and Martens 1998).

A number of external environmental factors are thought to affect the vector anophelines lifespan, and therefore their ability to complete the sporogonic cycle, including relative humidity, ambient temperature and rainfall. Environmental conditions optimal for *Anopheles gambiae* include temperature ranging between 20^0 and 30^0C, while the sporogonic development requires temperatures between 16^0 and 33^0C. Each *Plasmodium* species has a unique development rate from the time of gametocyte ingestion by a mosquito till the time sporozoites appear in the salivary glands. For instance, the incubation period for *P.falciparum* gets progressively shorter to around 9 days when the temperature is maintained at 30^0C whereas it takes around 23 days at 20^0C. On the other hand, *P.vivax* takes about 9 days at 25^0C for a complete sporogonic development compared to an average of 15 up to 20 days required for *P.ovale* and *P.malariae.* Areas and seasons with higher rainfall usually have higher malaria incidence than arid areas and seasons because of increased breeding habitat availability, moderated temperatures, and increased relative humidity. Elevation associated with cooler temperatures and lower humidity, limits transmission which consequently rarely occurs above 2000 meters (Carter and Mendis 2002, Drakeley *et al.* 2005, Hay *et al.* 2009, Reyburn *et al.* 2005).

The relatively high endemicity rate of malaria in Africa arises from the preferential feeding behaviors and biological characteristics of the main malaria vectors, as well as the prevailing high temperatures and relative humidity conditions. The number of blood meals a mosquito vector takes from human hosts is the product of the proportion of those taken from humans, the frequency with which the vector takes blood meals and the mean lifespan of the mosquito. The latter is a function of the rate at which individual blood meals are digested, which in turn has been shown to increase with increasing ambient temperature (Martens *et al.* 1995, Martens *et al.* 1997). The parasite requires sufficient time, between the blood meal that infects the mosquito and that which consequently passes the mature parasites to the next second host for those sporogonic stages, to complete their development. The main malaria vectors in Africa, namely *An.gambiae*, *An.arabiensis* and *An.funestus* are highly anthropophilic and well adapted to entering, resting and feeding inside houses (White 1974). Within the *Anopheles gambiae* species complex, the *Anopheles gambiae s.s* are predominantly anthropophilic feeding on humans both outdoors and indoors and are known to prefer resting indoors (endophilic) whereas *Anopheles arabiensis,* which is a primary but less potent as a malaria parasite vector, is equally zoophagic and readily feeds on cattle and rests outdoors (exophilic) (Bruce-Chwatt 1966b, Gillies and Coetzee 1987, White 1974). On the other hand *An.funestus* unique within its group in that it is consistently highly endophilic, endophagic and anthropophilic. These feeding and resting preferences have tremendous impact on human malaria transmission with levels expected to decline as one moves outside Africa where the vectors have been described as being more zoophagic so that feeding upon humans is only an occasional event in the life of a mosquito (Bruce-Chwatt 1966b).

As a result of these various forces, the global malaria burden is unevenly distributed (Figure 1.2.1), being concentrated in the tropical and sub-tropical regions of sub-Saharan Africa (Guerra *et al.* 2008, Hay *et al.* 2004, Hay *et al.* 2009, Kiswewski *et al.* 2004). While the unusually anthropophagic and endophilic habits of African malaria vectors underpin these intense transmission, these behavioural and feeding specializations are also key to the success of current priority measures (Insecticide treated nets (ITNs)/Long-lasting insecticidal nets (LLINs) or indoor residual spraying (IRS)) for the control and subsequent elimination of malaria: The same behaviours that place mosquitoes in close contact with humans inside houses, can readily be targeted with such insecticidal products that can be used in and around houses (Duchemin *et al.* 2001, Lindsay *et al.* 1993, Njiru *et al.* 2006, Okumu *et al.* 2012, Okumu *et al.* 2010, Takken and Knols 1999).

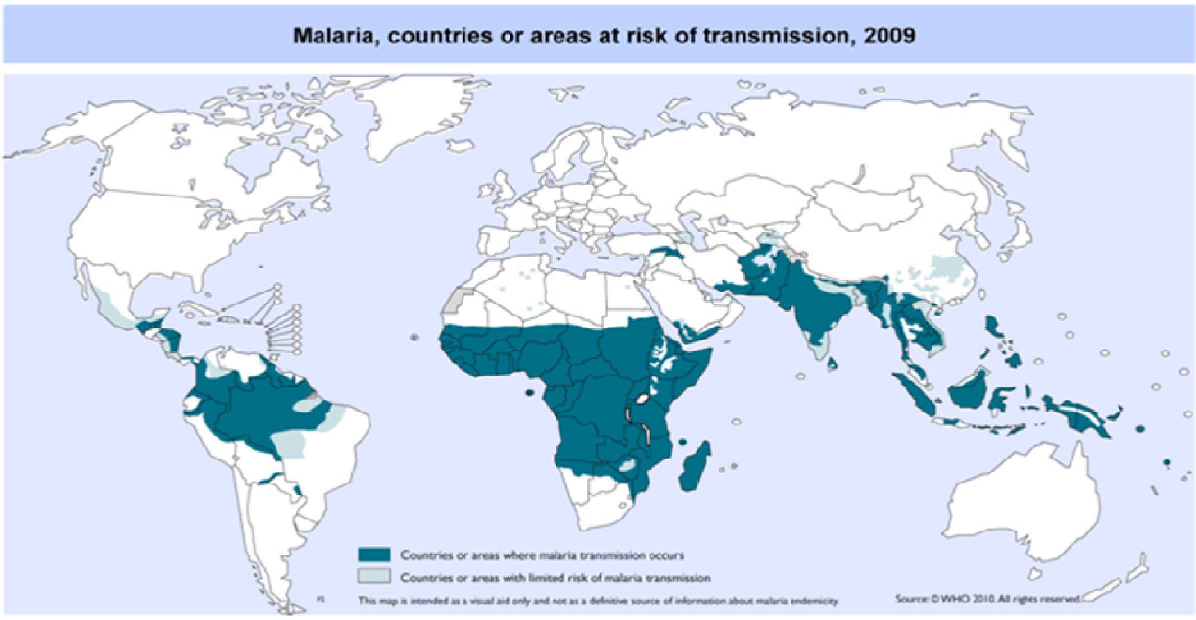

Figure 1.2.1: Global malaria risk distribution 2009 Source: World Health Organization 2011 (www.who.int/globalatlas)

1.3 Past, present and future of malaria control

Malaria can be controlled by reducing the disease burden by targeting the parasites inside the human host, using chemotherapy and vaccines. Alternatively, vector control aims at reducing man-mosquito contact through either larval source management with environmental management or larviciding or by killing or deterring adult mosquitoes with insecticides (LLINs or IRS) or physical barriers such as house screening. Malaria control has been a priority for the World Health Organization (WHO), Africa governments and external funding agencies for many years (Hay *et al.* 2009, WHO 2010). Historical successes of malaria elimination from Brazil (Killeen *et al.* 2002b, Soper and Wilson 1943), Egypt (Shousha 1948), North America and various parts of Europe (Kitron and Spielman 1989), as well as achievements of the first eradication campaign, and the more recent successes from various parts of Africa (Bhattarai *et al.* 2007, D'Acremont *et al.* 2010, Fegan *et al.* 2007, Geissbuhler *et al.* 2009, Kleinschmidt *et al.* 2009b, Nyarango *et al.* 2006, Shililu *et al.* 2003, WHO 2010), highlight how much malaria control efforts have achieved and can achieve. Based on the various available approaches, the WHO have formulated a global malaria control strategy with the objective of reducing world's burden of malaria (WHO 2000). To achieve these goals, the WHO and the Roll Back Malaria (RBM) partnership have developed the Global Malaria Action Plan (GMAP). The GMAP outlines a global framework for action to achieve substantial and sustained reduction of malaria burden in near and mid-term, as well as local elimination and, ultimately, global eradication in the longerterm (Najera *et al.* 2011, RBM 2008). The GMAP outlines universal coverage targets for all major control measures, to reduce malaria cases by 50% in 2010 and 75% by 2015, to reduce malaria deaths by 50% in 2010, malaria elimination in some countries by 2015 and subsequent total eradication through progressive elimination on a country-by-country basis. RBM has outlined a three-part global strategy to achieve these targets; (i) sustain control of malaria to reduce burden as long as possible (ii) eliminate malaria over time, one country at a time, and (iii) develop new tools and approaches to support the ongoing control and elimination efforts (Alonso *et al.* 2011c, Breman *et al.* 2011, Najera *et al.* 2011, RBM 2008).

1.3.1 Malaria control through environmental management in the first half of 20th Century

Evidence-based efforts to reduce the burden of malaria have been undertaken for more than a century. Malaria vector control by targeting immature larval and pupal-stage mosquitoes, through environmental management of their aquatic habitats, constituted the earliest human efforts to prevent malaria and has been applied successfully in a variety of settings around the world (Clyde 1967, Gorgas 1915, Keiser *et al.* 2005, Kitron and Spielman 1989, Soper and Wilson 1943, Utzinger *et al.* 2001, Walker and Lynch 2007, Watson 1953). Environmental management here refers to any planned physical activity that through land, water or vegetation transformation results in the prevention, reduction or ultimately elimination of disease vectors. Mosquito larval control strategies were considered the best proven primary means of suppressing malaria transmission until the mid 20th Century (Bruce-Chwatt 1987, Clyde 1967, Keiser *et al.* 2005, Kitron and Spielman 1989, Muturi *et al.* 2008). These strategies primarily control mosquitoes while still in their aquatic juvenile stages before they emerge, thereby reducing the emergence rate of host-seeking mosquitoes. Environmental management strategies which eliminate habitats also increase the amount of time required for adult vector to locate the oviposition sites and therefore increase their mortality rates and reduce their transmission potential (Gu *et al.* 2006, Killeen *et al.* 2004, Killeen *et al.* 2006c). Collectively these are described as larval source management (LSM) known to be the most efficient tools for vector control. Between the two World Wars larval control was almost the only method used for malaria control at large-scale in Africa (Kitron and Spielman 1989, Kouznetsov 1977). This could be done either through larval source reduction by manipulating the environment such as drainage of flooded areas and swamps, modification of river boundaries and vegetation clearance or through larviciding (Utzinger *et al.* 2001, Walker and Lynch 2007). Larval Source Management (LSM) strategies achieved impressive levels of control, and even the disappearance of malaria, in Palestine, Israel, Italy, America, and Africa (Clyde 1967, Kilama 1994, Kitron and Spielman 1989, Utzinger *et al.* 2001, Utzinger *et al.* 2002a, Watson 1953).

Moreover, larviciding which constitutes one among several other LSM strategies can be achieved by treating breeding sites with chemical or biological products commonly referred to as larvicides, that kill or debilitate the aquatic stages of insect species, (Geissbuhler *et al.* 2009, Kitron and Spielman 1989, Majambere *et al.* 2007, Rozendaal 1997, Walker and Lynch 2007). A number of chemical agents have been deployed successfully as malaria vector larvicides were commonly used before DDT became available in 1940s, including temephos, spenosid, petroleum oil, monomolecular films, copper acetoarsenite (Paris Green) (Clyde 1967, Rozendaal 1997). Moreover, an additional and distinct class of insect growth regulators (IGR) have also been deployed, including pyriproxyfen used for controlling both malaria and non-malaria vectors and the more recent results from Sri Lanka and Peru are highly encouraging (Braga *et al.* 2005, Darabi *et al.* 2011, Devine *et al.* 2009, Nayar *et al.* 2002, Walker 2002, Yapabandara and Curtis 2002, Yapabandara *et al.* 2001). Moreover, larval control has also been achieved using biological means, by introducing or manipulating naturally occurring organisms that regulate mosquito populations in the ecosystem through either parasitism or predation. Such biological agents include some bacterial formulations *Bacillus thuringiensis var israeliensis* (*Bti*) and *Bacillus sphaericus* (*Bs*) (Barbazan *et al.* 1998, Fillinger and Lindsay 2006, Fillinger *et al.* 2003, Majambere *et al.* 2007, Regis *et al*. 2000), as well as fish that feed on mosquito larvae (Chandra *et al.* 2008, Fletcher *et al.* 1992, Seng *et al.* 2008). Moreover, some fungal pathogens of the genera *Beauveria* and *Meterhizium* have also shown promising larvicidal properties against mosquito vectors (Mnyone *et al.* 2009, Mnyone *et al.* 2010, Mnyone *et al.* 2011, Scholte *et al.* 2006, Scholte *et al.* 2005). The successful elimination of an accidentally introduced, but well established, *An. arabiensis.* in north eastern Brazil using Paris green (Killeen 2003, Killeen *et al*. 2002b, Soper and Wilson 1943) and Egypt (Shousha 1948), as well as more recent success stories from Tanzania (Castro *et al*. 2004), Kenya (Fillinger *et al.* 2009) and Eritrea (Shililu *et al.* 2003) using these much more environmentally friendly bacterial agents are particularly encouraging.

However, despite all the success LSM had achieved, this method has largely failed to reduce transmission in most rural tropical areas, particularly in Africa (Majambere *et al.* 2010). There are a number of factors that led to this including, first and foremost, lack of sufficient expert human resources for implementing larval control on meaningful scales, as well as weak economies and poor infrastructures in most tropical African countries (Bruce-Chwatt 1987, Merritt *et al.* 1992, Walker and Lynch 2007). It should be understood here that the success of larviciding depends heavily on both timely and adequate information regarding the distribution of mosquito vector larvae complemented by repeated treatment of all potential breeding habitats on a regular basis (Killeen 2003, Killeen *et al.* 2006a, Killeen *et al.* 2002b, Rozendaal 1997, Service 1989). These requirements impose major implementation challenges, especially with regard to the rapid larval development and diverse nature of breeding habitats that are preferred by African malaria vectors from the *Anopheles gambiae* complex and underpin their widespread distribution (Gillies and DeMeillon 1968, Gillies and Coetzee 1987, Gladwell 2001).

1.3.2 Switching to adulticdes

The discovery of dichloro-diphenyl trichloroethane (DDT) in 1938, and other long-lasting residual insecticides during the early 1940s, stimulated formulation of the model that malaria prevalence might be more effectively reduced by targeting vector mosquitoes in their adult stage than in their aquatic larval stages (Bruce-Chwatt 1984, Bruce-Chwatt 1987, Garrett-Jones 1964, Gladwell 2001, MacDonald 1957, Muturi *et al.* 2008). This new paradigm rapidly and completely superceded larval control, and also reduced emphasis on vector behaviour studies, on the basis that malaria could be eliminated by exclusively targeting indoor-feeding mosquitoes (Bruce-Chwatt 1984, Garrett-Jones 1964, Gladwell 2001, Mabaso *et al.* 2004, MacDonald 1957, Muturi *et al.* 2008). The concept that insecticides delivered to human residences could result in dramatic suppression of the mosquito population vectorial capacity and malaria transmission intensity (Garrett-Jones 1964, MacDonald 1957), led to quick adoption of indoor residual spraying as the primary vector control method for malaria control (Gladwell 2001, Lengeler and Sharp, Mabaso *et al.* 2004, Walker and Lynch 2007). The ecological basis for such optimism (Garrett-Jones 1964, Garrett-Jones and Shidrawi 1969, MacDonald 1957) arises from the fact that the malaria parasite growing within a mosquito requires at least ten days to complete sporogony and become infectious, during which time the vector must also feed at least three times (Beier 1998, Warrell *et al.* 2002). Assuming that most blood meals taken by anthropophagic mosquitoes are obtained from humans inside houses while they are asleep, it is reasonable to expect that most mosquitoes would be exposed to such domestic insecticide formulation several times during that sporogonic incubation period. Furthermore, the concept that houses, and similar targets for adulticides, are easier to find and treat than aquatic habitats quickly led to the move from controlling larvae to controlling adult mosquitoes. It was therefore, envisaged that reasonable coverage of houses with residual insecticides would lead into complete interruption of the vectorial systems in a community by killing adult mosquitoes, hence reducing the proportion surviving the multiple blood meals required to reach an age at which they can become infectious and transmit *Plasmodium* parasites (Garrett-Jones 1964, Garrett-Jones and Shidrawi 1969, MacDonald 1957).

1.3.3 The rise and fall of the Global Malaria Eradication Program

The availability of cheap, effective long-lasting insecticides such as DDT and antimalarial drugs such as chloroquine (Bruce-Chwatt 1987, Najera *et al.* 2011, WHO 2008b), combined with oversimplified understanding of the ecology and epidemiology of malaria transmission systems (Garrett-Jones 1964, MacDonald 1957, Trigg and Kondrachine 1998), led to the adoption of the Global Malaria Eradication Programme (GMEP) in 1955 by the 8th World Health Assembly (WHO 1955). This campaign was based on the widespread use of DDT for indoor spraying to tackle adult mosquitoes and antimalarial drugs (chloroquine had also been established as a cost-effective option) to treat malaria and clear parasites from humans. Literally, eradication of any given pathogen refers to its complete disappearance from the globe with resulting zero incidence of infection (Greenwood 2008b, WHO 2008b). Achieving this ambitious goal for malaria depends on number of major pre-requisites including: 1) full understanding of the biology of disease vectors and parasite which often vary with epidemiological setting (Bruce-Chwatt 1987, Ferguson *et al.* 2010, Griffin *et al.* 2010), 2) availability of locally efficacious intervention options (Greenwood 2008a, Greenwood 2008b, Griffin *et al.* 2010, WHO 2008b), 3) long term commitment of both political and financial support from governments of all endemic countries and their overseas partners (Feachem and Sabot 2008, Mills *et al.* 2008, Sabot *et al.*, Tanner and Savigny 2008), 4) major improvement of health systems (Abel-Smith and Rawal 1992, de Savigny and Adam 2009, McIntyre *et al.* 2006) and 5) broad social economic development (Sachs and Malaney 2002, Tanner and Savigny 2008).

Although GMEP was initiated with a supposedly global agenda, it excluded most of sub-Saharan Africa with the exception of Ethiopia, South Africa and Zimbabwe (Feachem and Sabot 2008, Trigg and Kondrachine 1998, WHO 2008b), even though this is where the majority of malaria burden occurs (Guerra *et al.* 2008, Hay *et al.* 2004, Hay *et al.* 2009, Snow *et al.* 2005, WHO 2009). This region was excluded because of the limited health infrastructure and implementation capacity, as well such intensive transmission that even perfect implementation might not necessarily completely eliminate it (Bruce-Chwatt 1984, Bruce-Chwatt 1987, Trigg and Kondrachine 1998, WHO 2008b). Even where malaria control programs were launched in Africa, they were mostly concentrated on urban rather than rural settings, contrary to the stated strategy of the GMEP as it was implemented elsewhere. There are a number of speculations about how this policy was formulated and it is thought that these priorities were set because urban settings harboured economically important work forces, and because urbanization is associated with greater population density and economic development, thus enabling easier implementation (Schapira and Kumar 1989).

Malaria was successfully eliminated from most endemic developed countries, large areas of subtropical Asia and Latin America, as well as the highlands of Madagascar. At this point, it is important to distinguish between elimination and eradication: while the latter refers to global extinction of a pathogen, the more tractable former goal refers to local extinction from a specified area such as district, country, region or continent. Although the GMEP did not achieve its objective of malaria eradication, it removed the threat of malaria from over one billion people living where it was eliminated and greatly reduced the burden of malaria in many endemic countries outside Africa. However, challenged with lack of political will, limited resources and the resilient transmission systems of Africa and the pacific (Najera 2001, Najera *et al.* 2011, Sharma 1996, Trigg and Kondrachine 1998), it is not surprising that the programme fell far short of its local targets in many subtropical and tropical countries. The overall goal of global eradication was never achieved, and soon after the programme ended in 1967, malaria returned to areas where it had been temporarily eliminated (Bruce-Chwatt 1987, Feachem and Sabot 2008, Najera 2001, WHO 2008b). Other contributing factors to the collapse of this campaign included the increasing resistance of malaria vectors to insecticides, particularly DDT, and mosquito behavioural adaptations to avoid such pesticides (Curtis 2002, Molineaux and Gramiccia 1980, Najera *et al.* 2011, Soper 1965, WHO 2006a, Wyler 1983) and of malaria parasites resistance to drugs (Bruce-Chwatt 1987, Peters 1982, Soper 1965, Trigg and Kondrachine 1998). Resistance problems were attributed to the large scale use of antimalarial drugs and the overuse and misuse of DDT in agriculture, the enormous logistical challenges any program of such large scales faces, and rising costs of residual insecticides (Bruce-Chwatt 1987).

Recognizing these challenges, the twenty-second World Health Assembly re-assessed its strategy in 1969 and concluded that complete eradication remained the ultimate goal but that achievable levels of control was a more realistic, realizable target for the foreseeable future in those areas where elimination was not immediately feasible (Bruce-Chwatt 1987, Trigg and Kondrachine 1998, WHO 1969b, WHO 2008b), emphasizing effective use of available intervention options in each specific national context (Najera *et al.* 2011, Trigg and Kondrachine 1998, WHO 2008b). However, it was also concluded that existing tools were not sufficient to eradicate the disease in areas of intense transmission intensity, notably sub-Saharan Africa (Griffin *et al.* 2010, Molineaux and Gramiccia 1980, WHO 2008b). Consequently, this led the WHO (WHO 1969a) to lower its ambitious targets and extended its timelines for eradication indefinitely by changing its policy from eradication to sustained control (Molineaux and Gramiccia 1980, Trigg and Kondrachine 1998). The resulting loss of confidence and support among donors and governments for the programme resulted in a dramatic fall in funding and the capacity of most malaria endemic countries to continue with systematic malaria control. This led to the formal termination of the GMEP, with a wholesale reduction in financial support for antimalarial programs which started with the withdrawal of the US contribution in 1963 to the WHO Malaria Special Account, which represented more than 85% of the total budget (Najera 2001, Najera *et al.* 2011). As the flow of financial and technical support from the international community dried up, the WHO recommended that each malaria-endemic country should commit itself to establishing antimalarial activities in accordance with its available human, technical and financial resources, and to maintain these activities until the disease no longer posed a major public health problem (WHO 2008b). In practice most developing countries suffered from economic deterioration during the 1970s (Bruce-Chwatt 1987), particularly in Africa where most nations struggled with newly-acquired independence, so this transition to locally-sustained programmes was not successfully realized in practice. Consequently, malaria control programmes deteriorated dramatically during economic crisis of the 1970s, leading to aggressive resurgence of the disease across the tropics (Hay *et al.* 2002, Romi *et al.* 2002, Sharma 1996, Wyler 1983).

1.3.4 Revival of vector control for malaria prevention

The widely accepted, but over-simplified and over-optimistic notion, that malaria could be eradicated primarily by dichloro-diphenyl trichloroethane (DDT) spraying limited enthusiasm for vector biology among malariologists during the 1950s and 1960s (Najera *et al.* 2011, Zimmerman 1992). Few people were trained for careers in malariology, and the availability of research funds to examine the fundamental biology of parasite or vector populations was severely restricted. However, the alarming resurgence of malaria in the various tropical regions of the world during the 1970s, coupled with recognition of the mounting technical obstacles to successful control, renewed interest in malaria research and particularly vector biology (Najera *et al.* 2011, Zimmerman 1992). Malaria vector control was revived as a priority at policy level with the launching of the RBM partnership in 1998 (Dobson *et al.* 2000, Nabarro 1999). RBM began as a social initiative (Nabarro 1999) and has since received growing political support, including leaders of the G8 countries (Nabarro and Tayler 1998), as well as the signing of Abuja declaration by the heads of states of most African countries in the year 2000. The shared Abuja-RBM targets were to reduce malaria mortality by 50% by 2010 and negate malaria as a threat to world economies by 2015 (WHO Roll Back Malaria / 2003).

The origins of this revival lie in encouraging results from the first large scale trials of ITNs in The Gambia (Alonso *et al.* 1991), which were further re-enforced with subsequent series of randomized, controlled trials in stable, endemic African settings in Ghana (Binka *et al.* 1996), Kenya (Gimnig *et al.* 2003, Nevill *et al.* 1996, Phillips-Howard *et al.* 2003a, Ter Kuile *et al.* 2003a, ter Kuile *et al.* 2003b) and Burkina Faso (Habluetzel *et al.* 1997), proving that this tool is consistently effective in reducing overall morbidity and mortality among children. These breakthrough findings triggered a major shift in thinking that has seen confidence in vector control for malaria prevention grow steadily over the last two decades (Alonso *et al.* 2011a, Takken and Knols 2009), despite initial concerns about rebounding malaria as exposure and immunity diminishes (Reyburn *et al.* 2005, Snow and Marsh 2002). RBM has since promoted wide-spread use of ITNs, (Steketee and Campbell 2010, Steketee *et al.* 2008) or IRS where more appropriate, improved case management and intermittent preventive treatment of pregnant women, as its front-line priority strategies (RBM 2008). Interventions directed at killing vectors were restored to the malaria control agenda and are now increasingly implemented successfully on unprecedented scales through aggressive catch-up campaigns to achieve universal coverage in many African countries such as Tanzania, Ghana, Zambia and others in sub-Saharan Africa (Bhattarai *et al.* 2007, Chizema-Kawesha *et al.* 2010, Fegan *et al.* 2007, Noor *et al.* 2009, Noor *et al.* 2007, Steketee and Campbell 2010, Steketee *et al.* 2008, van Eijk *et al.* 2011, ZMoH 2009).

1.3.5 Scaling up ITNs/LLINs and IRS in the modern era

The current ongoing large-scale campaigns implemented by the national programmes under the umbrella of RBM, and supported by large-scale funders such as Global Fund Fight Against

AIDS, Tuberculosis and Malaria (GFFATM), World Bank and U.S President's Malaria Initiative (PMI), promote the effective implementation of proven vector control methods, specifically LLINs and IRS. These approaches both target adult mosquitoes and achieve massive impact for exactly the same ecological and epidemiological reasons that underpinned the GMEP: Their true value lies in killing off entire vector population, rather than personal protection, so high coverage of all age groups is essential (Hawley *et al.* 2003, Killeen *et al.* 2007, WHO 2007, WHO 2010). RBM has strengthened the capacity of national malaria control programmes by engaging endemic countries cohesively through bottom-up policy formulation and by progressively increasing financial and technical support from the international community (WHO 2008b). The distribution and use of ITNs is now the top priority vector control strategy in most African countries, with specific emphasis upon the advanced form of this technology that is now available, the LLINs (WHO 2007, WHO 2010, Yukich *et al.* 2007) which have a long life span and do not need re-impregnation with insecticides (Guillet *et al.* 2000). In a smaller group of mostly southern African countries, IRS is the front line vector control measure (Sharp *et al.* 2007b) but several countries implement various combinations of the two (Bhattarai *et al.* 2007, Chizema-Kawesha *et al.* 2010, Kleinschmidt *et al.* 2009a, WHO 2010, ZMoH 2009). Increasing coverage with proven vector control interventions such as LLINs or IRS, combined with availability and use of artemisinin-based combination therapies (ACTs), has dramatically reduced malaria burden in several African countries (Bhattarai *et al.* 2007, Ceesay *et al.* 2008, D'Acremont *et al.* 2010, Fegan *et al.* 2007, Kleinschmidt *et al.* 2009b, Noor *et al.* 2009, O'Meara *et al.* 2008, Okiro *et al.* 2007, WHO 2010). Socioeconomic growth in endemic countries, increased global financial support (Chizema-Kawesha *et al.* 2010, Kleinschmidt *et al.* 2009a, Steketee and Campbell 2010) and recent successful scale up of effective malaria control has inspired the malaria community to again consider the more ambitious goal of malaria eradication (Alonso *et al.* 2011a, Alonso *et al.* 2011b, Alonso *et al.* 2011c, Campbell and Steketee 2011, Feachem *et al.* 2010, Ferguson *et al.* 2010, Greenwood 2008a, Greenwood *et al.* 2008, Roberts L. and Enserink 2007, Steketee and Campbell 2010, Tanner and Savigny 2008). Although elimination of local transmission using existing tools (LLIN, IRS and ACTs) is considered feasible in some areas with relatively low transmission (John *et al.* 2009, Mabaso *et al.* 2004, Sharp *et al.* 2007a), it is extremely difficult to envisage with existing technology in high transmission settings (Ferguson *et al.* 2010, Griffin *et al.* 2010). In fact modelling analyses (Griffin *et al.* 2010) suggest that existing front-line measures will not even be sufficient to even push prevalence below the pre-elimination threshold level of 1% in holoendemic regions of Africa. Furthermore, recent reports from Senegal of rapid rebound of mosquito population, malaria transmission and disease burden, following the emergence of pyrethroid resistance are of grave concern (Trape *et al.* 2011).

1.3.6 Going beyond LLINs and IRS: Community based integrated vector management

LLINs and IRS are most effective against the anthropophagic, indoor-resting anopheline mosquitoes that are responsible for most malaria transmission in Africa (Govella *et al.* 2010b, Griffin *et al.* 2010, Pates and Curtis 2005). However, the major challenge to this approach has been the emergence of vector strains that are resistant to the only class of insecticides approved for net impregnation namely the pyrethroids (Kelly-Hope *et al.* 2008, Trape *et al.* 2011), coupled with behavioural adaptations of the malaria vectors to avoid pesticide contact by feeding outdoors (Bugoro *et al.* 2011, Govella *et al.* 2010b, Reddy *et al.* 2011, Russell *et al.* 2011a). A number of reports from both the GMEP era and recent phase of intradomiciliary vector control scale up, suggest that behavioral adaptations such as day-time and outdoor-biting habits (Braimah *et al.* 2005, Bugoro *et al.* 2011, Geissbühler *et al.* 2007, Molineaux and Gramiccia 1980, Reddy *et al.* 2011, Russell *et al.* 2011a, Taylor 1975) limit the effect of these control measures (Govella *et al.* 2010b, Griffin *et al.* 2010). Moreover, insufficient expert local capacity for implementation of these priority vector control measures, the limited number of available cost-effective and safe insecticides, and the huge challenges associated with achieving effective delivery and coverage, all undermine the impact these two measures can achieve in practice. Where malaria vectors are exophagic and have adapted to feeding outdoors, old-fashioned larval control strategies may be particularly valuable (Govella *et al.* 2010b, Shililu *et al.* 2004). It is increasingly considered important to evaluate the potential role of alternative vector-control tools, such as larval source management (LSM), that act outside of houses and can stop mosquito proliferation at source.

1.4. Opportunities for community-based larval source management

All the historical success stories of past LSM programs were vertically organized and were initiated, funded and implemented by central governments (Soper and Wilson 1943). As a result, most of them failed to achieve sustainable viability because they were implemented as stand-alone programs that did not engage the relevant local communities. While community involvement in efforts to control vector-borne diseases has recently become popular among malariologists (Agyepong 1992, Castro *et al.* 2004, Chaki *et al.* 2011, Kidane and Morrow 2000, Manderson 1992, Manderson *et al.* 1989, Ruebush 2nd and Godoy 1992), the concept has been widely applied as a central component in the planning, implementation and evaluation of most control efforts in addressing a number of primary health care challenges (Oakley 1989a, Oakley

1989b, Rifkin 1985, Rifkin 1996, Rifkin *et al.* 1988) and certain vector-borne diseases such as *Ae. aegypti* in the Americas and Asia, as well as community development initiatives (Heintze *et al.* 2007, Kay and Nam 2005, Seng *et al.* 2008). It is widely recognized that, while participatory approaches may require greater upfront investment in staff training and operational expenditures, the overall costs are often lower than in programs that exercise top-down approach with no local capacities involved (Korten 1980, Narayan-Parker and Ebbe 1997). Moreover, community involvement is thought to not only address resource limitations and inequities in developing countries, but also to enhance availability and accessibility of health services (Manderson *et al.* 1989, Mukabana *et al*. 2006, Service 1993a, Townson *et al*. 2005, Winch *et al.* 1992). Generally, malaria control is considered to have a great potential for community involvement since the range of control strategies such as LLINs distribution, IRS application and LSM can all be safely applied through community participation. The fact that many vertically-organised vector control programs have had limited success because of weak engagement of the grass-roots community base (Manderson *et al.* 1989, Mukabana *et al.* 2006, Service 1993a, Townson *et al.* 2005, Winch *et al.* 1992) is suggestive of a need to adopt a different strategy as we enter this new era of integrated vector management (IVM) containing multiple vector control tools. It has consistently been elucidated that these obstacles are not due to a lack of medical, epidemiological or ecological technical knowledge, but rather a lack of knowledge on how to achieve effective coverage through widespread involvement of the communities in question (Killeen *et al.* 2006c, Mukabana *et al.* 2006, Oakley 1989a, Toledo *et al.* 2007). It is increasingly acknowledged that community involvement can improve intervention affordability, coverage, efficiency and effectiveness as well as promote equity and self-reliance (Heintze *et al.* 2007, WHO 1983, Winch *et al*. 1992).

1.4.1 Integrated vector management

The current global agenda for intensified malaria-control efforts has suggested the delivery of multi-intervention packages for the control of vector borne diseases. The WHO has therefore called for the promotion of integrated vector management (IVM), to combat malaria (Beier *et al.* 2008, WHO 2004, WHO 2012). IVM refers to the integration of different approved, affordable vector control methods that reduce the malaria disease burden through rational and optimal use of available resources. These options are chosen on the basis of existing knowledge on local vector bionomics, environment, ecosystem, and disease transmission patterns as well as the human and institutional capacities available. Currently, the most widely adopted IVM strategies combination of ITNs or IRS with limited LSM and health education (Beier *et al.* 2008, WHO 2004). Despite the various advantages and success in some areas (Barat 2006, Chanda *et al.* 2008, Fillinger *et al.* 2009), the implementation of IVM packages is absent for most developing countries because of a lack of stable funding arising from a weak evidence base for effectiveness on large scales. Even where funds and stakeholder buy in, are not limiting absence of sustainable effective and rigorously-evaluated modes for governance and evidence-based management, that incorporate decentralized procedures for implementation, monitoring and evaluation, has proven prohibitive. Although the IVM global strategic framework is designed to overcome some of these problems, in practice this still has proven a difficult concept to implement in practice (Beier *et al.* 2008, Killeen *et al.* 2006c). Despite all the challenges, IVM has potential as an effective, environmentally friendly and long-lasting malaria control strategy. LSM may be a particularly useful option for a component of IVM for establishing and sustaining community-based vector control programs (Fillinger *et al.* 2009, Walker and Lynch 2007, WHO 2004). In addition, larval control has the advantage over adult control in that larvae have much lower mobility than adults so they cannot avoid interventions such as excito-repellent insecticides (Killeen *et al.* 2002a, Killeen *et al.* 2011, Muirhead-Thomson 1960, Pates and Curtis 2005). Effective larval control depends primarily upon the acquisition of adequate information regarding the distribution of vector larvae and their aquatic habitats (Rozendaal 1997). A common challenge facing larval control is the heterogeneity in the larval habitat requirements among the distinct vector species and even among siblings of the same species; consequently larval control approaches between two different locations may vary greatly (Gillies and DeMeillon 1968, Gillies and Coetzee 1987, Himeidan *et al.* 2009, Killeen *et al.* 2006c, Konradsen *et al.* 2004, Minakawa *et al.* 2005a, Minakawa *et al.* 2006, Minakawa *et al.* 2005b, Soper and Wilson 1943). Larviciding is considered to be readily feasible and more effective in places where breeding habitats are relatively fewer and readily identified and treated, typical of most urban and peri-urban areas (Keiser *et al.* 2004, Lines *et al.* 1994, Walker and Lynch 2007). Although a few recent studies have yielded promising results (Fillinger *et al.* 2009, Fillinger *et al.* 2008, Shililu *et al.* 2007, Shililu *et al.* 2003), large-scale application of larvicides in Africa has remains a challenge given the heterogeneity and extensive number of breeding habitats, which makes repeated treatments difficult and expensive to undertake (Fillinger *et al.* 2008, Killeen *et al.* 2006c, Mukabana *et al.* 2006).

1.4.2 Environmental management

Early malaria control efforts in the first half of the 20th century primarily involved targetting mosquito breeding habitats. Predominantly, this involved environmental management (EM) to eliminate habitats, as well as more focal species sanitation to reduce mosquito abundance, through modification or manipulation (Ault 1994, Rozendaal 1997, Utzinger *et al.* 2001). Some of the earlier success stories in Italy, USA, Malaysia, Zambia and Indonesia were primarily large-scale environmental modification projects and were implemented prior to 1940s (Keiser *et al.* 2005, Kitron and Spielman 1989, Konradsen *et al.* 2004, Watson 1953). More recent environmental management programs for controlling malaria have involved the renovation of abandoned drainage systems in Dar es Salaam, Tanzania (Castro *et al.* 2009, Castro *et al.* 2010, Castro *et al.* 2004), Uganda (Lindsay *et al.* 2004) and Zambia (Walker and Lynch 2007). The efficacy of environmental management procedures for controlling mosquito larvae depends very much on how well they are matched to specific ecological characteristics of the local vector population, as well as on the initial planning process, institutional set up, and implementation of programs. Deployed as a malaria control strategy, EM has particular potential for successful implementation through community-based initiatives (van den Berg and Knols 2006). The majority of mosquito proliferation sites for important vectors of malaria in Africa are man-made (Chaki *et al.* 2009, Matthys *et al.* 2006, Mutuku *et al.* 2006, Sattler *et al.* 2005, Yohannes *et al.* 2005) so community engagement is seen as crucial to ensuring that beneficiary communities understand their role in sustaining or eliminating vector breeding sites.

1.4.3 Larviciding

Apart from EM, LSM can also be achieved by treating breeding sites with chemical or biological agents that kill or debilitate the aquatic stages, commonly referred to as larvicides (Kitron and Spielman 1989, Rozendaal 1997, Walker and Lynch 2007). Over the last century a range of chemical larvicides and biological control have been employed for malaria vector control with notable success against the major African vectors in Zambia, Egypt and Brazil (Killeen 2003, Shousha 1948, Soper and Wilson 1943, Utzinger *et al.* 2001, Watson 1953). The efficacy of any larviciding agent is often dependent upon a number of factors including formulation type, water quality, the susceptibility of targeted mosquito species and persistence in the environment. For instance, due to its low toxicity and short environmental persistence temephos has been widely applied for routine malaria vector control in India and Mauritius. By comparison the high toxicity level of Paris green, which was successfully deployed to eliminate of *Anopheles arabiensis* from northeast Brazil and the Nile valley of Egypt (Killeen 2003, Killeen *et al.* 2002b, Shousha 1948, Soper and Wilson 1943) caused several deaths of program staff and was banned from extensive usage for public health applications. In any case such controversial active ingredients have now been rendered obsolete by the availability of much safer options such as oils, temephos and non chemical larvicides.

In comparison with most chemical larvicides, biological control agents are advantageous in terms of their low toxicity to humans and other non-target organisms (Priest 1992, Regis *et al.* 2000). However their relatively short persistence in the environment and the dynamic nature of habitat distribution implies repeated treatment at short intervals (Killeen *et al.* 2002b, Walker and Lynch 2007). This necessarily increases costs and operational logistic challenges demanding much larger teams of organized and readily available human resources. Two mosquitocidal bacterium strains *Bacillus thuringiensis var. israelensis* and *Bacillus sphaericus* are probably the most widely-exploited bacterial species used as larvicides and have both proved highly efficacious and effective against *Anopheles* and non-anopheline mosquitoes, as well as other Diptera with aquatic stage larvae (Fillinger and Lindsay 2006, Fillinger *et al.* 2003, Geissbuhler *et al.* 2009, Lacey and Undeen 1986, Lacey and Lacey 1990, Majambere *et al.* 2007, Shililu. *et* *al.* 2003). The low toxicity to both humans and the environment, coupled with simple application procedures, such as hand application of granules or backpack spraying of water dispersible formulations, gives microbial larvicides a significant advantage over chemical larvicides for community-based larviciding (Fillinger *et al.* 2008).

1.4.4 Monitoring and evaluation of malaria vector control programmes

Public health surveillance involves ongoing systematic collection, analysis and interpretation of outcome-specific data for use in the planning, implementing, monitoring and evaluating public health practice (Brownson *et al.* 1999, Teutsch and Thacker 1995, Thacker *et al.* 2010). Disease surveillance often brings together health information and management functions within health programmes. A surveillance system encompasses data collection, processing, reporting, and use by relevant stakeholders that ultimately affects daily program practice, and implementation as well as policy (German *et al.* 2001, Teutsch and Thacker 1995). Such a system is often important for improving our understanding of health service delivery strengths and weaknesses, which in turn helps to optimize program effectiveness and efficiency through improved operations. The success of any surveillance system, in its broader sense, depends on a number of basic features including simplicity, flexibility, data quality, acceptability, sensitivity, positive and negative predictive value, representativeness, timeliness and stability (Thacker *et al.* 2010). Simple and effective health information systems are envisaged as being key to enabling disease control efforts, through appropriate allocation of resources and also by enabling inclusive decision-making and human resource management that deliver inputs where and when needed (Thacker *et al.* 2010). A smoothly functioning health information system that optimizes the delivery of effective interventions should be geared to address the prevailing disease burden levels and existing health information gaps (Breman *et al.* 2004, Castro *et al.* 2004, Guerra *et al.* 2008). Disease surveillance strategies are highly dependent on the type and level of disease within specified populations at risk (Thacker *et al.* 2010, Thurmond 2003).

Increased investments in malaria control efforts over recent years have triggered resurgence in the demand for better management of health information for resource allocation as more countries achieve substantive levels of control and several even enter the pre-elimination phase (Alonso *et al.* 2011c, Brabin *et al.* 2008, Feachem *et al.* 2010, Greenwood 2008b, Snow *et al.* 2008). The rather ambitious goals for malaria control and subsequent elimination require that significant additional resources are mobilized. Apparently for many of the countries most severely afflicted by malaria, baseline data and reliable monitoring of key impact indicators are scarce or absent. There is therefore an urgent need for developing cost-effective monitoring and evaluation systems for malaria control generally (de Savigny and Binka 2004) and vector control in particular (Fillinger *et al.* 2008).

Recent advances in malaria control have led to increasing reports of declining malaria mortality and morbidity and the associated malaria vector densities (Bhattarai *et al.* 2007, D'Acremont *et al.* 2010, Feachem *et al.* 2010, Fegan *et al.* 2007, O'Meara *et al.* 2010). As a result it is becoming increasingly difficult to measure some disease or infection indicators using the conventional tools such as cross-sectional parasite surveys which were developed for use in high transmission settings. This necessitates improved surveillance systems for malaria generally, and vector control in particular, that focus on detecting infections and characterizing transmission dynamics (Breman *et al.* 2001, Breman *et al.* 2004, de Savigny and Binka 2004, Lee *et al.* 2010).

Surveillance systems are typically differentiated into two overlapping streams of activity namely monitoring and evaluation (M&E). Monitoring encompases routine tracking of the key indicators of program performance (inputs to outputs) to inform day-to-day management and optimization. In contrast, evaluation is the periodic assessment of the impact achieved by an intervention program. In other words, evaluation strives to link impact or a particular output or outcome directly to an intervention within specified period of time. While disease monitoring helps public health managers determine which areas or systems require more input, and identify process changes which might contribute to an improved response, evaluation assists them to determine the effective epidemiological impact of a specific intervention. In a well-designed surveillance system, monitoring indicators contribute greatly towards evaluation. Health systems in general and more specifically, data systems and management functions can become significant epidemiologic and infection risk determinants, because when they are effective, they promote rational decision making and resource allocation (Alilio *et al.* 2004, Starfield *et al.* 2005). Successes in a particular health information structure directly translate into improved result-based management, service delivery and epidemiological impact. The success of such disease surveillance systems depend on the adequate and timely flow of information (Buehler *et al.* 2004, German *et al.* 2001).

As malaria burden drops in response to LLIN and IRS scale up, surveillance becomes increasingly important, but also correspondingly more difficult, in order to identify persistent foci of infection for targeting additional control tools. Furthermore, these new tools, by definition, require additional monitoring indicators to enable effective delivery management. Larval control also requires quite specific ecological understanding of the major vector species and their distinctive interaction with the local environment on very fine spatial scales (Killeen *et al.* 2002b, Killeen *et al.* 2006c, Mukabana *et al.* 2006). Management burden is also exacerbated by the need for technical understanding of the principles and practice of labour-intensive larvicide application or environmental management under challenging field conditions (Killeen *et al.* 2002b, Killeen *et al.* 2006c, Mukabana *et al.* 2006, Townson *et al.* 2005). Sustainable systems for monitoring the abundance and distribution of aquatic mosquito stages are required to enable timely decisions and actions by managers responsible for such programmes. This represents a particular challenge in Africa where the most important vectors from the *Anopheles gambiae* can develop from egg to adult in less than a week, in habitats which can be transient and difficult to detect (Dongus *et al.* 2007, Fillinger *et al.* 2008, Gillies and DeMeillon 1968, Mutuku *et al.* 2009, Soper and Wilson 1943, Vanek *et al.* 2006). Larvicide application requires unusually intensive monitoring because success and failure occurs on remarkably fine spatial (< $1km^2$) and temporal scales (1 week) that match to the retreatment cycles and geographic division of responsibility to individual staff.

1.5 Opportunities for developing community-based larval source management systems in Urban Dar es Salaam, Tanzania

During the GMEP era, the community's role in malaria control was dominated by compliance and cooperation with insecticide spraying, as well as drug prophylactic and treatment regimes, and the provision of labour for their implementation (Winch *et al.* 1992). Today, the envisaged participation role for communities in vector-borne disease control has dramatically changed following the Alma-Ata declaration (WHO 1978). Community participation is now considered to be context-dependent, reflecting the prevailing interactions between the human population, vector population and ecological settings, as well as local social, economic and political contexts (Espinol *et al.* 2004, Madan 1987, WHO 2006a, Winch *et al.* 1992). Furthermore, the degree of community involvement is often determined by the type of disease targeted, intervention options available, and the endemicity level (Madan 1987, Okanurak *et al.* 1992, Rifkin 1996, Toledo *et al.* 2007). The constituent activities of vector control can be implemented intermittently, as with IRS or ITN distribution campaigns, or routinely, as is the case for larvicide application (Fillinger *et al.* 2008, Killeen *et al.* 2006c, Mukabana *et al.* 2006, Townson *et al.* 2005). Based on the heterogenous and often unpredictable nature of mosquito proliferation, in a wide variety of water bodies that are often enclosed within walled or fenced compounds, the success and sustainability of larval control relies very much on community understanding, willingness and involvement (Kitron and Spielman 1989, Toledo *et al.* 2007, Winch *et al.* 1992).

1.5.1 Cities as ideal settings for development, evaluation and scale up of larval source management

High population density associated with relatively few mosquito breeding sites, which are well defined and easily located, characterise most urban settings (Fillinger *et al.* 2008, Keiser *et al.* 2004, Robert *et al.* 2003, Walker and Lynch 2007). Moreover, stronger institutional support, governance and infrastructure offer significant advantages for establishing and sustaining vector control programmes in urban areas. Area-wide application of vector control strategies may therefore be more practical and affordable in urban areas. Traditionally, malaria research and control has focused on rural areas until it was recently recognized to also pose a major problem in urban settings which are home to an increasing proportion of the world's population (Guerra *et al.* 2006, Hay *et al.* 2005, Keiser *et al.* 2004, Lines *et al.* 1994, Robert *et al.* 2003). Increasing attention is now being devoted to the growing problem of urban malaria arising from rapid growth of urban areas due to high rates of rural-urban migration (McMichael 2000). Although malaria vector population densities might be relatively low, and likewise the probability of malaria infection, both stable and unstable transmission occurs in urban settings where malaria remains significant problem (Trape *et al.* 1992). Specialized intervention packages that include enhanced surveillance activities and intensified anti-vector interventions are thus needed for urban areas where it may be possible to develop more ambitious programs than are currently realistic in rural areas (Dongus *et al.* 2011a, Dongus *et al.* 2007, Kiswewski *et al.* 2004, Robert *et al.* 2003).

Success in past urban malaria control programs (UMCPs) has often been linked to environmental management strategies (Bang *et al.* 1975, Clyde 1962, Clyde 1967, Keiser *et al.* 2004, Kilama 1991a, Kilama 1994, Mukabana *et al.* 2006, Phillips 1993) and simultaneous implementation of affordable surveillance methods. Other factors underpinning success included (1) context-specific tailoring of packages of complementary interventions that stressed adaptability and were fine-tuned over time to minimize the number of malaria cases per year, (2) long term commitment to programme development: 3 to 5 years were allowed for a given package of interventions to exhibit high level performance; (3) the presence of program staff knowledgeable on aspects of malaria ecology, epidemiology, entomology, and hydrology (Clyde 1962, Keiser *et al.* 2004, Phillips 1993). Notably, essentially all the programs involved communities in one way or another, in environmental management and larviciding activities for controlling the locally-relevant vectors of malaria (Mukabana *et al.* 2006).

1.5.2 A brief history of larval source management in urban Dar es Salaam, Tanzania

Urban malaria control in Tanzania, just like in several other African countries, dates back almost a century to the time when the area was still under German rule (Bang *et al.* 1977, Castro *et al.* 2004, Clyde 1967, Kilama 1991a, Mukabana *et al.* 2006). Despite major financial constraints, particularly during the economic crisis of the early 1970s, some form of urban-specific malaria control programme has generally been maintained in Tanzania for most of the time since then (Castro *et al.* 2004, Orenstein 1914, Schilling 1910). Historically, diverse and well-planned intervention programs were implemented by colonial governments and private entrepreneurs (Clyde 1967, Watson 1953, Wolff 1994). A combination of EM, larviciding, mosquito-proofing houses, personal protective measures, and antimalarial drugs were used (Castro *et al.* 2004, Mukabana *et al.* 2006). As a means to enhancing sustainability and effectiveness of malaria control efforts, the Germans introduced the first ever EM intervention during the early part of the 19th Century, which involved mainly soil drainage (Clyde 1961a, Clyde 1961b, Kilama 1991a). However, the difficult terrain of Dar es Salaam characterized by low land levels, exacerbated by frequent tides, resulted in the formation of water bodies and a conducive environment for mosquito proliferation, even during the dry season (Kilama 1991a). The technical, operational and financial challenges involved made this such a difficult undertaking that the German ordinance for mosquito extermination was formulated in 1913 (Beck 1977, Schilling 1910). Among other things, this ordinance authorized legal sanctions for the destruction of all standing water sources including ponds, tins and coconut shells, as well as filling and oiling water bodies, drain construction and spraying houses. From 1918 up to 1961, when Tanganyika as mainland Tanzania was known at the time was a British protectorate following World War I, malaria control efforts were continued through the Royal Army Medical Corps. There were a number of interventions that were tried during this era consisting mainly of EM measures such as drainage, straightening of streams, cleaning of the banks of drains and rivers, oiling of ponds, puddles and swamps, and introduction of predatory fish and larvicidal arial spraying (Clyde 1967, Kilama 1991a). Much stronger legal measures were introduced, for instance those ensuring that cattle were kept far from streams and swamps (Kilama 1991a). Malaria control in urban Dar es Salaam and other towns in Tanzania continued to rely heavily upon community-implemented larviciding and EM measures such as drainage, filling, oiling and other engineering works, supplemented with community health education, resulting in limited malaria transmission levels well into the post independence period (Bang *et al.* 1975, Bang *et al.* 1977, Clyde 1961a, Kilama 1991a).

Soon after independence in 1961, malaria control continued to rely on LSM strategies that began during the colonial period (Bang *et al.* 1975, Beck 1977, Clyde 1961a, Clyde 1961b, Kilama 1991a) up to 1972 when adverse economic conditions, combined with rapid, poorly planned decentralization, led to deterioration of the health system generally (Kilama 1994). Larviciding and environmental management were maintained by a centralized vector control service well into the post-independence period up to 1972 (Bang *et al.* 1975, Bang *et al.* 1977, Kilama 1991a, Kilama 1994). In 1971 the Dar es Salaam City Council in collaboration with the WHO East African *Aedes* Research Unit, launched an integrated package of interventions combining EM, IRS and community health education to simultaneously target three mosquito vector genera *Anopheles*, *Culex pipiens fatigans* and *Aedes* (Bang *et al.* 1975). The program was considered to be highly effective and cost effective as it tapped into the readily available local labour force (Bang *et al.* 1975).

Moreover an evaluation undertaken 13 months afterwards had shown that the strategy had achieved significant success in terms of mosquito density reductions (Bang *et al.* 1975). However, this initiative included no maintenance of drains so water flow was blocked by silt, vegetation and waste, providing suitable breeding grounds for mosquitoes (Castro *et al.* 2004). As a result, the mean mosquito densities in urban Dar es Salaam increased up to ten fold by the early 1980s and remained so until 1983, when the Ministry of Health and Social Welfare (MoHSW) of Tanzania reformulated its malaria control policies, with the priority of integration of multiple complementary interventions, including vector control, chemotherapy, and monitoring of drug resistance (Kilama 1991b). In 1987, the government of Japan, through the Japan International Cooperation Agency (JICA), in collaboration with the government of Tanzania, initiated an eight year Urban Malaria Control Programme (UMCP) in Dar es Salaam and Tanga, focusing primarily on vector control (Castro *et al.* 2004). A campaign against aquatic mosquito larval stages was launched through regular chemical larviciding and EM with the latter focusing primarily in rehabilitating the existing drainage systems to complement indoor residual spraying (IRS), ultra low volume space spraying and ITN distribution. This achieved significant reductions of mosquito proliferation by lowering the water table of most waterlogged areas in the city. Furthermore, polystyrene beads were also used to control Culicine larvae in pit latrines and soakage pits (Castro *et al.* 2004, Chavasse *et al.* 1995). Apart from providing technical and operational expertise, this JICA-directed programme was also responsible for identification of larval habitats, distribution of equipment for malaria control, entomological monitoring and parasitological evaluation (Castro *et al.* 2004). Despite demonstrating that integrated vector management could be successfully implemented, this program could not be sustained due to lack of long term financial commitment and poor institutionalisation of planning and management functions so it officially collapsed in 1996. Nevertheless, it provided a useful learning experience, demonstrating how successful malaria control programs depend not only on the available interventions options and financial support available, but also on stable local managerial capacity and stakeholder acceptance (Barat 2006, Castro *et al.* 2004). The lack of integration with the City Council institutional structure explains why this JICA-driven project was not sustained in the long term (Castro *et al.* 2004, Mukabana *et al.* 2006). Not long after the closure of this program, the Urban Health Project (UHP) was initiated in Dar es Salaam (Atkinson *et al.* 1999, Harpham and Few 2002, WorldBank 1993) in response to the international calls to recognize and deal with the likely effects of rapid urbanization on health in developing countries (Atkinson *et al.* 1999, Harpham and Few 2002, WorldBank 1993). The UHP brought about the strengthening of the health care and general public health infrastructure in Dar es Salaam and witnessed a number of health sector reforms which enabled effective implementation of the decentralized health system (Harpham and Few 2002, Mtasiwa *et al.* 2003). It is upon these institutional foundations laid down by the UHP that the current Urban Malaria Control Program (UMCP) was initiated (Mukabana *et al.* 2006).

1.5.3 The contemporary Urban Malaria Control Programme (UMCP)

The UMCP in Dar es Salaam was initiated by the Dar es Salaam City Council to develop sustainable and affordable systems for larval control as part of routine municipal services (Castro *et al.* 2009, Castro *et al.* 2010, Dongus *et al.* 2011a, Dongus *et al.* 2007, Fillinger *et al.* 2008, Geissbuhler *et al.* 2009, Mukabana *et al.* 2006, Vanek *et al.* 2006). UMCP's aims were (1) to strengthen the ability of the municipalities to deliver interventions prioritized by the National

Malaria Control Program, and (2) to provide support for adding further interventions focusing on LSM. Specifically, the UMCP implements three main tasks, (1) routine aquatic habitat surveillance, (2) regular application of microbial larvicides *Bti* and *Bs*, and (3) adult mosquito monitoring (Fillinger *et al.* 2008, Geissbuhler *et al.* 2009). These were preceded by comprehensive participatory mapping of the study area on the ground by community members who prepared hand drawn sketch maps that were later formalized and integrated into electronic geographic information systems using aerial photographs (Dongus *et al.* 2011a, Dongus *et al.* 2007).

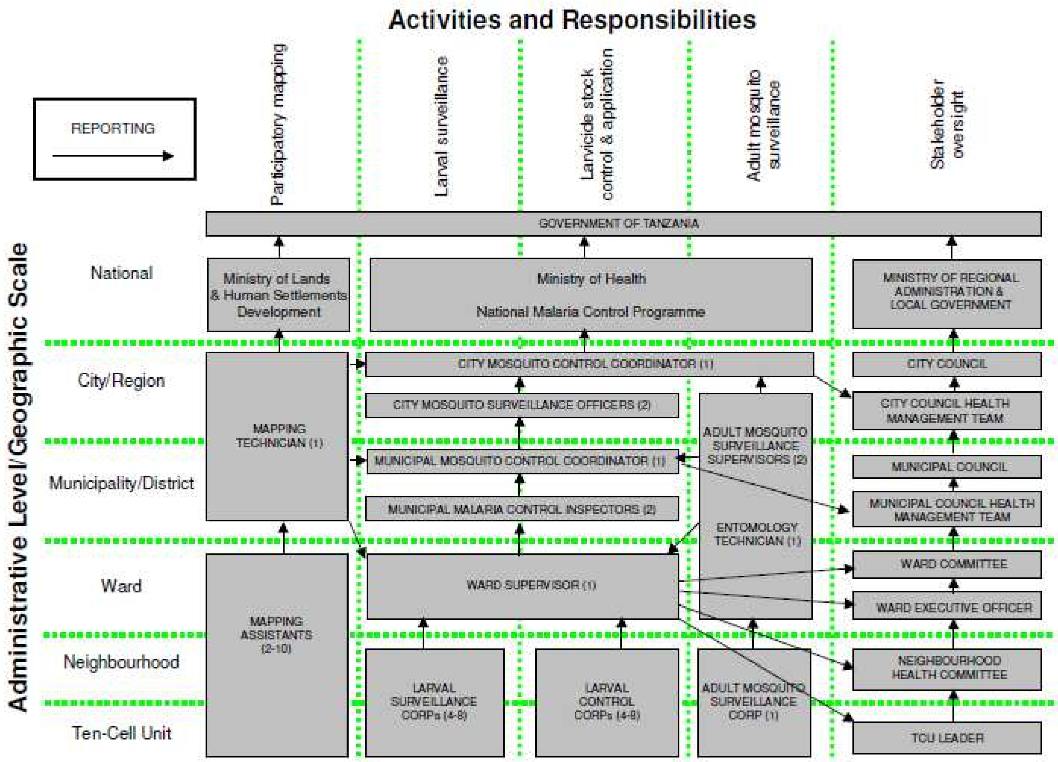

Figure 1.3.1: Reporting structure of the UMCP, presented as a matrix of activities which are hierarchically layered over a range of spatial and administrative scales (Fillinger *et al.* 2008). The numbers presented in brackets describe the number of personnel assigned to each post in

each administrative subunit rather than level (e.g. 2 municipal inspectors at each of 3 municipalities means that a total of 6 should be working for the programme at any time).

All UMCP activities were fully integrated into the decentralized administrative system in Dar es Salaam (Figure 1.3), thus operating on all five administrative levels of the city: the city council, municipalities, wards, neighbourhoods (refered to as *mitaa* in Kiswahili, singular *mtaa*), thousands of ten-call units (TCU) and their respective plots (Dongus *et al.* 2011a, Dongus *et al.* 2007, Dongus *et al.* 2009, Fillinger *et al.* 2008). The main tasks of the four upper levels are project management and supervision, whereas the actual surveillance and control of mosquitoes is organized and implemented at the level of smallest administrative unit of local government namely wards, neighbourhoods and TCUs. The decentralized field activities of the UMCP are implemented by modestly remunerated community members, who are referred to as Community Owned Resource Persons (CORPs) (Dongus *et al.* 2007, Fillinger *et al.* 2008, Mukabana *et al.* 2006, Vanek *et al.* 2006). The CORPs were recruited through the local administrative leadership, including the ward excutive officers, street chairmen and the respective Community Health and Environmental Committees (CHEC). Fifteen wards (five from each of the three municipalities) were included in the Dar es Salaam UMCP (Figure 4), encompassing as wide a variety of geographical and socioeconomic settings as possible. In total, an area of 55 km^2 was covered with wards ranging in size from 0.96 to 1.5 km^2 with a human population exceeding 614,000 in 2010, (Anonymous 2003b, UN 2010). UMCP began systematic larviciding in April 2006, in 3 wards (one from each municipality) and larvicide application was scaled up to 9 wards in May 2007 and all 15 wards in March 2008.

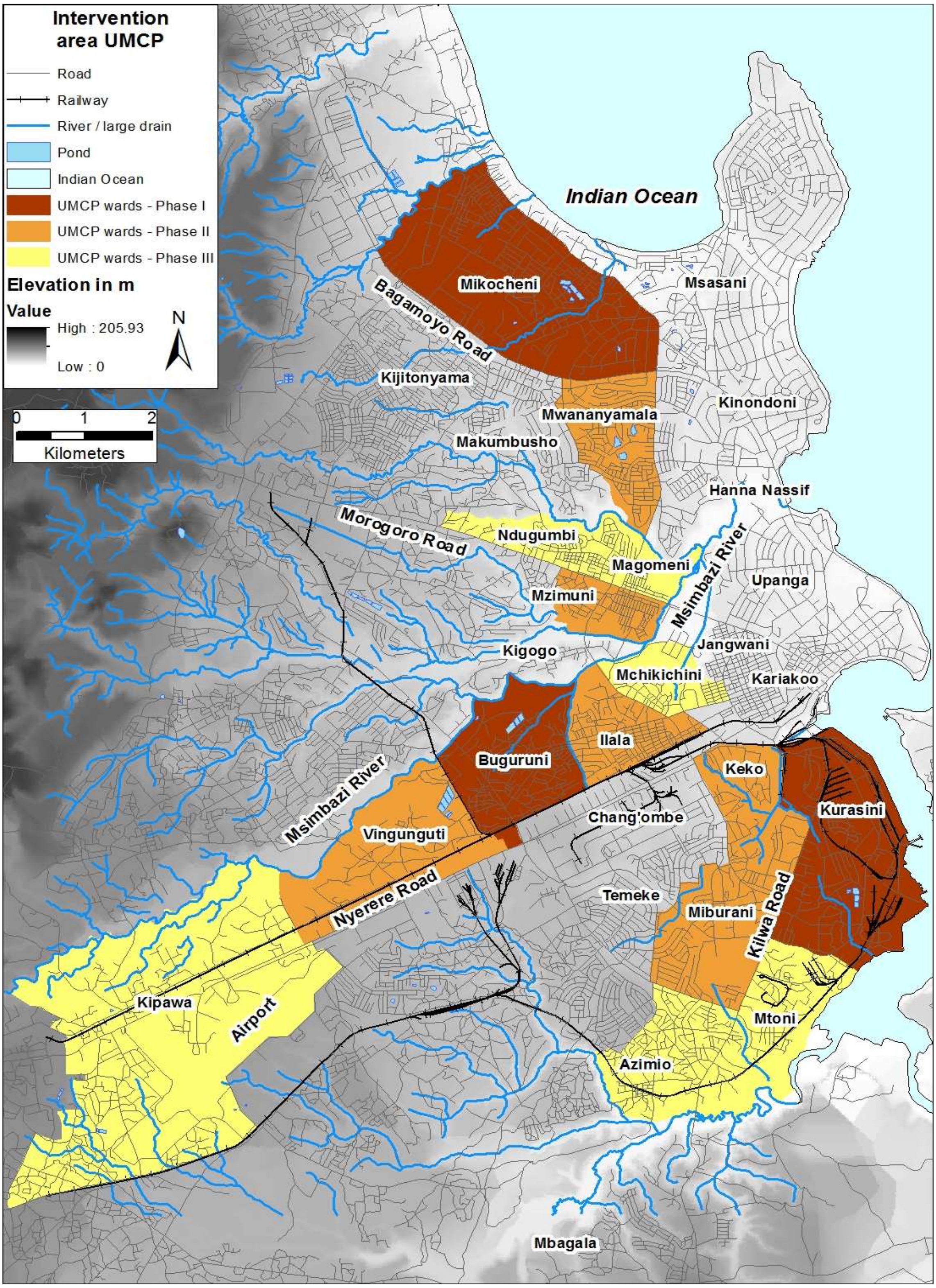

Figure 1.5.1: Map of Dar es Salaam, showing the location of the respective UMCP wards with different colours depicting the various subsequent phasing of the larviciding intervention

1.6 Goal and Objectives

The goal of this study was to demonstrate that well designed, managed and organized larval control programme relying on community-based surveillance and intervention procedures can be feasibly implemented in Dar es Salaam and can provide a model to many other growing African cities. In attempting to address this general question, the following specific objectives were addressed.

1.7 Specific objectives

i) To assess the effectiveness of larval surveillance by community owned resource persons (CORPs).

ii) To compare and contrast the performance of larval surveillance CORPs recruited by and working within their home communities with those who were not.

iii) To evaluate the epidemiological predictive power and cost-effectiveness of a community-based adult mosquito surveillance system.

iv) To assess the evolving roles and responsibilities of communities and institutions in the programme.

CHAPTER TWO

ACHIEVING HIGH COVERAGE OF LARVAL-STAGE MOSQUITO SURVEILLANCE: CHALLENGES FOR A COMMUNITY-BASED MOSQUITO CONTROL PROGRAMME IN URBAN DAR ES SALAAM, TANZANIA

This paper has been published in *Malaria Journal* 2009,8.

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2.0 Abstract

Background

Preventing malaria by controlling mosquitoes in their larval stages requires regular sensitive monitoring of vector populations and intervention coverage. The study assessed the effectiveness of operational, community-based larval habitat surveillance systems within the Urban Malaria Control Programme (UMCP) in urban Dar es Salaam, Tanzania.

Methods

Cross-sectional surveys were carried out to assess the ability of community-owned resource persons (CORPs) to detect mosquito breeding sites and larvae in areas with and without larviciding. Potential environmental and programmatic determinants of habitat detection coverage and detection sensitivity of mosquito larvae were recorded during guided walks with 64 different CORPs to assess the accuracy of data each had collected the previous day.

Results

CORPs reported the presence of 66.2% of all aquatic habitats (1,963/2,965), but only detected *Anopheles* larvae in 12.6% (29/230) of habitats that contained them. Detection sensitivity was particularly low for late-stage *Anopheles* (2.7%, 3/111), the most direct programmatic indicator of malaria vector productivity. Whether a CORP found a wet habitat or not was associated with his/her unfamiliarity with the area (Odds Ratio (OR) [95% confidence interval (CI)] = 0.16 [0.130, 0.203], P<0.001), the habitat type (P<0.001) or a fence around the compound (OR [95%CI] = 0.50 [0.386, 0.646], P<0.001). The majority of mosquito larvae (Anophelines 57.8 % (133/230) and Culicines 55.9% (461/825) were not reported because their habitats were not found. The only factor affecting detection of Anopheline larvae in habitats that were reported by

CORPs was larviciding, which reduced sensitivity (OR [95%CI] = 0.37 [0.142, 0.965], P=0.042).

Conclusions

Accessibility of habitats in urban settings presents a major challenge because the majority of compounds are fenced for security reasons. Furthermore, CORPs under-reported larvae especially where larvicides were applied. This UMCP system for larval surveillance in cities must be urgently revised to improve access to enclosed compounds and the sensitivity with which habitats are searched for larvae.

2.1 Background

Historically, most vector control efforts for malaria prevention in Africa have focused almost exclusively on adult stages, specifically IRS (Kouznetsov 1977, Mabaso *et al.* 2004) and ITNs (Lengeler 2004, WHO 2006a, WHO 2008a). However, with increasing insecticide resistance (Cobel *et al.* 2007, Kelly-Hope *et al.* 2008) and behavioural change by mosquito vectors (Geissbühler *et al.* 2007), development and evaluation of complementary vector control strategies remains a priority. Reviews of the early 20th century programmes in Brazil, Zambia and Egypt (Shousha 1948, Soper and Wilson 1943, Watson 1953), have highlighted dramatic reductions of malaria burden achieved by integrated vector management generally and mosquito larval control specifically (Killeen 2003, Killeen *et al.* 2002b, Utzinger *et al.* 2001, Utzinger *et al.* 2002a). Application of microbial larvicides, such as *Bacillus thuringensis* var. *israelensis* (*Bti*), to larval habitats offers a control option that cannot be avoided by mosquitoes (Killeen *et al.* 2002a, Muirhead-Thomson 1960) and that has low probability of developing resistance due to the complex mode of action of the larvicide (Wirth *et al.* 1998, Wirth *et al.* 2004). Furthermore, recent successes in urban Tanzania (Geissbuhler *et al.* 2009), the highland of western Kenya (Fillinger *et al.* 2009) and in Eritrea (Shililu *et al.* 2003), suggest that larval control may be a valid option for malaria vector control in selected eco-epidemiological settings.

Rapid growth of cities, characterized by a distinctive mix of different social, economic and cultural conditions is an important feature of contemporary African countries (Hay *et al.* 2005, Keating *et al.* 2003, Keiser *et al.* 2004, Knudsen and Slooff 1992). High population density associated with relatively few breeding sites suggests that area-wide application of vector control strategies is more practical and affordable in urban areas (Robert *et al.* 2003, Walker and Lynch 2007). Moreover, stronger institutional support, governance and infrastructure offer significant advantages for establishing and sustaining vector control programmes in urban areas. However, the heterogeneity and mobility of the human population renders most urban communities less cohesive and therefore difficult to mobilize *en masse* to achieve impact of public health interventions. Malaria vector proliferation, transmission intensity and burden in urban areas is highly heterogeneous and focal, (Donnelly *et al.* 2005, Guerra *et al.* 2006, Keiser *et al.* 2004, Robert *et al.* 2003, Wang *et al.* 2006). Despite its growing importance, it is only recently that urban malaria is receiving the attention it deserves (Hay *et al.* 2005, Keiser *et al.* 2004, Robert *et al.* 2003).

Cities and large towns are regarded as some of the most favourable environments for sustainable mosquito larval control, because mosquito-breeding sites are defined and easily located. However, larval control requires quite specific ecological understanding of the major vector species and their distinctive interaction with the local environment on very fine spatial scales (Killeen *et al.* 2002b, Killeen *et al.* 2006c, Mukabana *et al.* 2006). Additionally, technical understanding of the principles and practice of larvicide application or environmental management, as well as intensive labour under challenging field conditions, are essential (Killeen *et al.* 2002b, Killeen *et al.* 2006c, Mukabana *et al.* 2006, Townson *et al.* 2005). Sustainable systems for monitoring the abundance and distribution of aquatic mosquito stages are required to enable effective decisions and actions by managers responsible for such programmes. This represents a particular challenge in Africa where the primary vector, *Anopheles gambiae,* can develop from egg to adult in less than a week in habitats, which can be ephemeral and difficult to detect (Gillies and DeMeillon 1968, Mutuku *et al.* 2009, Vanek *et al.* 2006).

Larval control for malaria prevention, delivered primarily through human resources mobilized from within local communities, has been recommended to minimize cost and maximize sustainable scalability (Fillinger *et al.* 2008, Killeen *et al.* 2006c, Mukabana *et al.* 2006, Townson *et al.* 2005). However, given the technical, logistic and coverage requirements of larval control, which are probably greater than for current priority measures, such as insecticide-treated nets or indoor residual spraying, community-led rather than merely community-based vector control may be difficult to achieve (Fillinger *et al.* 2008, Killeen *et al.* 2006c, Vanek *et al.* 2006). A more sustainable approach might be the blending of vertical and horizontal strategies for the implementation of community-based systems for delivering area-wide control measures. Such an approach might rely on extensive mobilization of community-based labour integrated into vertical management systems implemented by centralized institutions (Fillinger *et al.* 2008, Killeen *et al.* 2006c, Vanek *et al.* 2006). It is important to identify and understand the social and environmental factors that influence human behaviour and consequently the effectiveness of such programs.

The Urban Malaria Control Programme (UMCP) in Dar es Salaam has been initiated by the Dar es Salaam City Council as a pilot programme to develop sustainable and affordable systems for larval control as part of routine municipal services (Fillinger *et al.* 2008, Geissbuhler *et al.* 2009, Govella *et al.* 2009, Mukabana *et al.* 2006, Sikulu *et al.* 2009, Vanek *et al.* 2006). An in-depth look at the environmental and programmatic determinants of surveillance coverage in this urban environment was conducted to identify strengths, weaknesses and opportunities for improvement.

2.2 Methodology

2.2.1 Study area

Dar es Salaam is Tanzania's biggest and most economically important city with the current population size exceeding 2.5 million inhabitants and a total area of 1,400 km^2, corresponding to a mean human population density of 2,900 per km^2 (Anonymous 2003b) . It is situated between latitude 6.0°–7.5° S and longitude 39.0°–39.6° E. The city is divided into three municipalities: Kinondoni, Temeke and Ilala and each of these municipalities is further divided into wards. The study site comprised the 15 wards with 614,000 residents (Anonymous 2003b) included in the Dar es Salaam UMCP, (Fillinger *et al.* 2008, Geissbuhler *et al.* 2009, Geissbühler *et al.* 2007, Mukabana *et al.* 2006) covering an area of 55 km^2 with wards ranging in size from 0.96 to 15 km^2. All UMCP activities are coordinated by the City Medical Office of Health, and are fully integrated into the decentralized administrative system in Dar es Salaam, operating on all six administrative levels of the city: the city council, the three municipal councils it oversees, 15 wards chosen from those municipalities, containing 67 neighbourhoods referred to as *mitaa* in Kiswahili (singular *mtaa*, meaning literally street), and more than 3,000 housing clusters known as ten-cell-units (TCU) with each of them subdivided into a set of plots corresponding largely to housing compounds. The main tasks on the three upper levels are programme management and supervision, whereas mosquito larval surveillance and control is organized at ward level and implemented at the level of TCUs and their constituent plots. In principle, a TCU clusters ten houses with an elected representative known as an *mjumbe*, but typically comprises between 20-

100 houses in practice (Dongus *et al.* 2007). UMCP implements regular surveillance of mosquito breeding habitats as a means to monitor effective coverage of aquatic habitats with microbial larvicides. Surveillance is applied through a community-based (Vanek *et al.* 2006) but vertically managed delivery system (Fillinger *et al.* 2008). The cross-sectional surveys described here to evaluate routine surveillance activities were conducted between end of June 2007 and January 2008. This period spanned a full dry season and was preceded by a typical rainfall pattern with a main rainy season from March to June and a much shorter rainy season from October to December.

2.2.2 Routine programmatic larval surveillance by community based personnel

Community owned resource persons (CORPs) were recruited through local administrative leaders including Street Health Committees and were remunerated at a rate of 3,000 Tanzanian shillings (US$ 2.45) per day through a casual labour system formulated by the municipal councils of Dar es Salaam for a variety of small-scale maintenance tasks such as road cleaning and garbage collection (Mukabana *et al.* 2006, Vanek *et al.* 2006). All essential standard operating procedures adopted by the recruited larval surveillance CORPs are described in detail elsewhere (Fillinger *et al.* 2008), but summarized as follows.

Over 90 larval surveillance CORPs were actively employed by the UMCP during the time of survey with each assigned to a defined area of responsibility, comprising a specific subset of TCUs within one neighbourhood. These lists of TCUs were initially allocated to individual CORPs based on local knowledge of habitat abundance, difficulty of terrain and geographic scale and subsequently refined through detailed participatory mapping of the study area (Dongus *et al.*

2007). On average, one CORP was responsible for an area of approximately 0.6 km^2. All CORPs worked under the oversight of a single ward-level supervisor. Each CORP followed a predefined schedule of TCUs, which they were expected to survey on each day of the week. In wards where larviciding was taking place, the schedule of TCUs visited by the surveillance CORPs followed one day after the application of microbial larvicides by a separate set of larval control CORPs (Fillinger *et al.* 2008) so that indicators of operational shortcoming, such as the presence of late-stage (3^{rd} or 4^{th} instar) mosquito larvae, could be reacted to in sufficient time to prevent emergence of adult mosquitoes. This system was designed for routine mosquito habitat surveillance and larviciding to allow timely interpretation and reaction to entomologic monitoring data.

Figure 2.2.1 community-based implementation of the UMCP roles: Comprehensive larval surveillance (**A**), Quality control larval surveillance (**B**), Larvicide application by hand (**C**) and blowers (**D**) and Routine Entomological Monitoring using the Ifakara Tent Trap (**E**)

2.2.3 Qualitative preliminary assessment of community-based larval surveillance

The investigator (PPC) initially conducted three weeks of unscheduled guided walks with 23 of the surveillance CORPs nominated by the ward supervisor after the investigator reported to their office in the morning. The investigator did not pre-inform the CORPs nor did he reveal his role and independent status at any time before or during the visit. Both the investigator and the chosen CORPs would leave the ward office and survey TCUs that the CORPs were expected to survey according to their normal predefined schedule for that particular day (Fillinger *et al.* 2008), returning later to report to the ward supervisor. At this stage, the survey was led by the CORPs and the investigator followed passively, covertly observing and recording how CORPs conducted their routine larval habitat surveillance and prepared their daily reports for submission to the ward supervisor. Specifically, the following information was collected: did CORPs follow TCUs schedule correctly, were all TCUs and plots visited, whether fenced compounds were entered and if not, why not, how habitats were recorded, how habitats were searched for larvae, how CORPs interacted with residents. In cases of observed shortcomings in the operational practices of the CORPs or any additional opportunities for improved implementation of their duties, the CORPs were informally advised by the investigator. This approach was intended to maintain an open, non-authoritative relationship of the investigator with the CORPs, allowing him to observe and understand the operational challenges facing the CORPs and the program as a whole. A detailed formal analysis of these qualitative observations will be published elsewhere but informal appraisal of these observations was used to design a quantitative survey described as follows.

2.2.4 Quantitative cross-sectional evaluation of community-based larval surveillance

A total of 173 TCUs from neighbourhoods distributed across all 15 wards were randomly selected from the list of TCUs in the UMCP study area. A total of 64 CORPs were responsible for these selected TCUs. The investigator accompanied the relevant CORP in guided walks through each TCU one day after their scheduled routine surveillance of that TCU and implemented his own larval habitat surveys following the standard operating procedures (Fillinger *et al.* 2008). Results of the investigator were compared with the CORP's datasheet of the previous day. Every potential habitat found by the CORP in each plot, and any additional habitats identified by the investigator that had not been detected by the surveillance CORPs, were distinguished and recorded using standardized forms (Appendix 1). Habitats were further classified into three habitat categories and constituent 11 habitat types (Vanek *et al.* 2006) as follows: (1) natural habitats comprising (i) marshy or swampy areas, (ii) river-beds and (iii) springs or seepages; (2) agricultural artificial habitats comprising (i) rice paddies, (ii) ridge and furrow agriculture (*matuta*) and (iii) other habitats associated with agriculture; (3) non-agricultural artificial habitats comprising (i) drains and ditches, (ii) construction pits, foundations and other excavations (iii) water storage containers, (iv) tyre tracks and puddles and (v) ponds or pools. Additional information was collected regarding the presence or absence of a fence around a plot and whether or not a particular TCU was targeted with larvicide application at the time that it was surveyed. Lastly, records were taken regarding evidence of lack of familiarity of a CORP with the specific TCU and plots. Unfamiliarity was assumed if the CORP was not readily able to find his or her way around the TCU or plot, when plot boundaries could not be clearly defined and/or when residents of the plot were unable to recognise him/her as a regular visitor to the area.

2.2.5 Statistical analyses

All the data were entered in coded numeric form and analysed using SPSS 15.0. Any association between the occupancy of different mosquito habitat categories and types by *Anopheles* and Culicine larvae was analysed using multivariate binary logistic regression (Collett 2003). Specifically, generalized estimating equations (GEE) were fitted to determine the influence of lack of familiarity of the CORP with the area, presence of a fence around the plot and whether larviciding was operational in that time and place upon the proportion of wet habitats (detection coverage) reported by CORPs and the proportion of habitats which contained larvae that were reported to be occupied by the CORP (detection sensitivity) for different habitat categories or types. While all observed habitats were included in the model fits to assess detection coverage, only those found to contain larvae by the investigator were considered in the denominator of models to assess detection sensitivity. The detection of the wet habitat or larval occupancy by the CORP was treated as the binary outcome variable and was fitted to a binomial distribution with a logit link function. CORP identity was treated as the subject variable and an exchangeable correlation matrix chosen for the repeated measurements distinguished by plot identity as the within subject variable. Differences between frequency distributions were assessed using likelihood ratio χ^2 analysis.

2.3 Results

2.3.1 Habitat characteristics found during cross-sectional evaluation

A total of 8,395 plots were visited during the cross-sectional surveys, 60.0% (5,039) of which were from larviciding areas. Approximately one quarter of these plots (26.8%; 2,253) was behind fences. There was an unequal distribution of fenced plots between the visited larviciding and non-larviciding areas with the majority of the fenced plots (69.7%; 1,571) recorded in areas where larviciding was taking place. Overall 3,997 potential mosquito breeding habitats were recorded. Of these, 2,965 (74.2%) contained water at the time of survey. The vast majority of these wet habitats were non-agricultural artificial habitats (90.0%), such as drains, ditches, construction sites, foundations, man-made holes and tyre tracks. The remainder was composed of a small number of natural habitats (7.4%), such as swampy areas with high groundwater level, riverbeds, seepages and springs, and a few agricultural artificial habitats (2.6%) mainly associated with rice and sweet potato cultivation; crops grown in ridge and furrow systems known as *matuta* (Table 2.3.1).

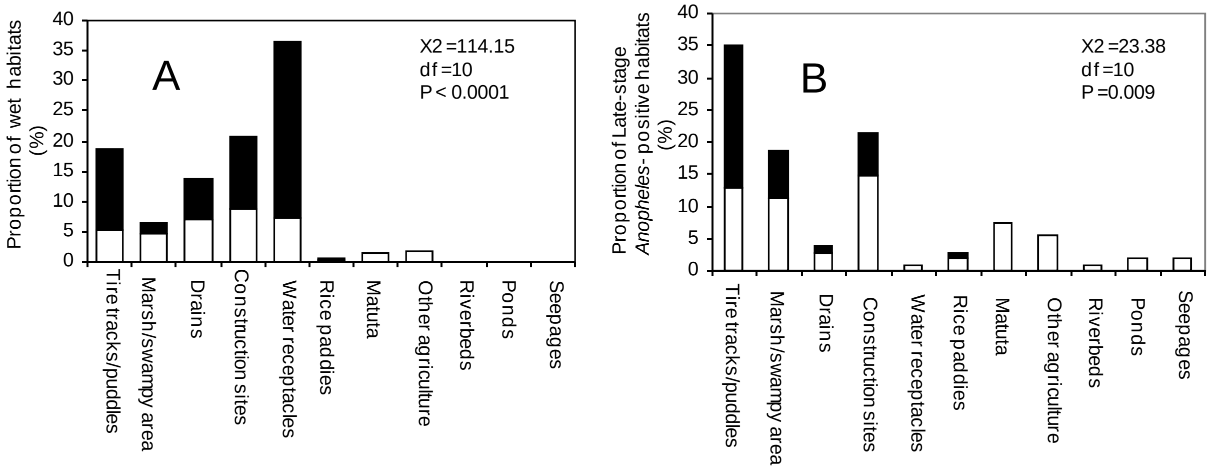

Figure 2.3.1 Proportions of wet habitats (A) and late-stage *Anopheles*-positive habitats (B) found by CORPs within fenced (Black bars) and unfenced (White bars) plots

Almost half (45.6%; 1,351/2,965) of all aquatic habitats were located within fenced plots. One fifth (20.5%; 608/2,965) of all aquatic habitats were recorded in plots with which CORPs clearly appeared to be unfamiliar and 91.9% (539/608) of these were located behind fences (Figure 2.3.1). A large number of wet habitats were surveyed in both larviciding areas (1,895) and in non-larviciding areas (1,070) and the proportion of habitats within fenced plots was higher in areas with larviciding than those without (50.8% (962) versus 36.4% (389), respectively; χ^2 = 57.3, df=1, P<0.001).

Table 2.3.1: Occupancy of different mosquito habitat categories and types by all stages of *Anopheles* and *Culicine* larvae.

Variables	*Anopheles* larvae occupancy			Culicine larvae occupancy		
	Proportion occupied % (n/N)[a]	OR [95%CI]	P	Proportion occupied % (n/N)[a]	OR [95%CI]	P
Natural Habitats	***28.64 (63/220)***	***1.00***[b]	***NA***[b]	***20.00 (44/220)***	***1.00***[b]	***NA***[b]
Marsh/swampy areas	36.25 (58/160)	1.00[c]	NA[c]	11.88 (19/160)	1.00[c]	NA[c]
Riverbeds	8.33 (2/24)	0.38 [0.09,1.64]	0.192	95.83 (23/24)	137.54 [18.17, 1041.38]	<0.001
Seepages/springs	8.33 (3/36)	0.38 [0.11,1.26]	0.113	5.56 (2/36)	0.35 [0.08,1.51]	0.160
Agricultural artificial habitats	***43.42 (33/76)***	***1.91 [1.12,3.28]***	***0.019***	***22.37 (17/76)***	***1.15 [0.61, 2.17]***	***0.660***
Rice paddies	71.48 (5/7)	10.33[1.96,54.39]	0.006	14.28 (1/7)	0.99 [0.12, 8.46]	0.998
Matuta	47.06 (16/34)	3.67 [1.78,7.57]	<0.001	29.41 (10/34)	2.49 [1.12, 5.52]	0.025
Other agriculture	34.39 (12/35)	2.16 [1.02,4.55]	0.044	17.14 (6/35)	1.24 [0.49, 3.13]	0.653
Non-agricultural artificial habitats	***5.06(135/2669)***	***0.13 [0.09, 0.19]***	***<0.001***	***28.81(769/2669)***	***1.60 [1.14,2.26]***	***0.007***
Tyre tracks/puddles	19.48 (68/349)	2.35 [1.55,3.57]	<0.001	14.33 (50/349)	0.81 [0.46,1.42]	0.454
Drain	1.96 (21/1070)	0.84 [0.05,0.14]	<0.001	20.84(223/1070)	1.60 [1.15, 2.24]	0.006
Construction sites	6.25 (42/672)	0.27 [0.18,0.41]	<0.001	31.55 (212/672)	2.70 [1.92,3.80]	<0.001
Water storage containers	0.34 (2/587)	0.01[0.003,0.058]	<0.001	47.36 (278/587)	5.34 [3.80, 7.51]	<0.001
Ponds	18.18 (2/11)	0.92 [0.19,4.35]	0.914	54.55 (6/11)	7.18 [2.11, 24.40]	0.002
Total	***7.79(231/2965)***	***NA***	***NA***	***27.99(830/2965)***	***NA***	***NA***

The proportion of wet habitats found by investigator to contain *Anopheles* and Culicine larvae; Odds ratio (OR) and P values for the likelihood of occupancy determined with a binary logistic regression treating habitat category or type as potential determinants.

[a] N is the total number of all wet habitats found during cross-sectional surveys while n is the number of either Anopheles or Culicine larvae positive habitats found

[b] is the reference group for comparing habitat categories,

[c] is the reference group for comparing the habitat types,

CI = confidence interval

NA; Not applicable

Only 7.8% of all the surveyed habitats contained any aquatic stages of *Anopheles* larvae (Table 2.3.1) so there were relatively few habitats in which the sensitivity with which CORPs detected these key indicators of malaria vector proliferation could be assessed. Unexpectedly, three quarters (74.8%, 172/230) of anopheline-occupied habitats were found in larviciding areas and anopheline larval occupancy was twice as high in wards where larviciding took place as those without (9.1% (172/1,895) versus 5.5% (59/1,070); Odds Ratio [95% Confidence Interval] = 2.11 [1.20-3.67], P=0.009). Overall, 7.0% (207/2,965) of wet aquatic habitats contained early-stage (1st and 2nd instars) *Anopheles* larvae, whereas 5.2% (155/2,965) of aquatic habitats were inhabited by late-stage *Anopheles* larvae (3rd and 4th instars), with 71.6% (111/155) of the latter recorded in areas with larviciding.

The probability of a habitat containing Anopheline larvae depended on category and habitat type (Table 2.3.1). Agricultural sites were twice as likely to contain Anopheline larvae than natural habitats, whilst the chance of finding larvae in artificial non-agricultural habitats was much lower. Nevertheless, non-agricultural artificial habitats were the most abundant (90%) and, therefore, constituted 58% (135/231) of all *Anopheles*-occupied habitats (Table 2.3.1).

Over one quarter of wet habitats contained culicine larvae (Table 2.3.1), with 25.9% (767) and 22.1% (656) inhabited by early-stage and late-stages respectively. Natural and agricultural habitats were equally likely to harbour culicine larvae whilst the probability of their presence was significantly higher in artificial, non-agricultural habitats (Table 2.3.1).

2.3.2 CORPs’ detection of aquatic habitats

CORPs recorded 1963 wet habitats during their routine surveillance. Seven of these habitats were confirmed to be non-existent by the investigator, suggesting these CORPs had filled the surveillance forms without visiting the relevant plots so these were excluded from the analyses. Therefore, CORPs correctly recorded two thirds of wet habitats (Table 2.3.2). Detection coverage varied significantly between individual CORPs and between different habitat types ($P<0.001$ for both as determined by logistic regression). CORPs were unfamiliar with 20.5% (608) of wet habitats and 92% (539) of these were located behind fences. Furthermore, the majority of wet habitats that the CORPs failed to record (61.1%; 619/1009) were located within fenced plots.

Table 2.3.2. Detection efficiency of different aquatic mosquito larval habitat types and categories by CORPs.

Habitat Category	Habitat type	Total number of wet habitats detected by		Proportion detected by CORPs (%)
		CORPs	Investigator	
Natural Habitats	Marsh/swampy areas	93	160	58.1
	Riverbeds	24	24	100.0
	Seepages	29	36	80.6
	Subtotal	***146***	***220***	***66.4***
Agricultural artificial habitats	Rice paddies	3	7	42.9
	Matuta	23	34	67.6
	Other agriculture	18	35	51.4
	Subtotal	***44***	***76***	***59.9***
Non-Agricultural artificial habitats	Tyre tracks/puddles	176	349	50.4
	Drains	898	1050	85.5
	Construction sites	450	672	67.0
	Water storage containers	231	587	39.4
	Ponds	11	11	100.0
	Subtotal	***1766***	***2669***	***66.2***
Total		**1956**	**2965**	**66.0**

CORPs; community-owned resource persons

Detection coverage differed significantly for different habitat types (χ^2=432.8, df=10, p<0.001) and categories (Table 2.3.3) with artificial non-agricultural habitats 1.6 times more likely to be recorded than others (Table 2.3.3). Consistent with the baseline evaluation (Vanek *et al.* 2006) conducted before the introduction of current procedures for mapping (Dongus *et al.* 2007), surveillance and larvicide application (Fillinger *et al.* 2008), most conspicuous habitat types like ponds, rivers, seepages, springs and drains were more readily recorded, whereas water receptacles were poorly detected (Table 2.3.2). Furthermore, the type of habitats that CORPs did not find was significantly different between the fenced and unfenced plots: the majority of water storage containers, tyre tracks and artificial pits were located behind fences (Figure 2.3.2).

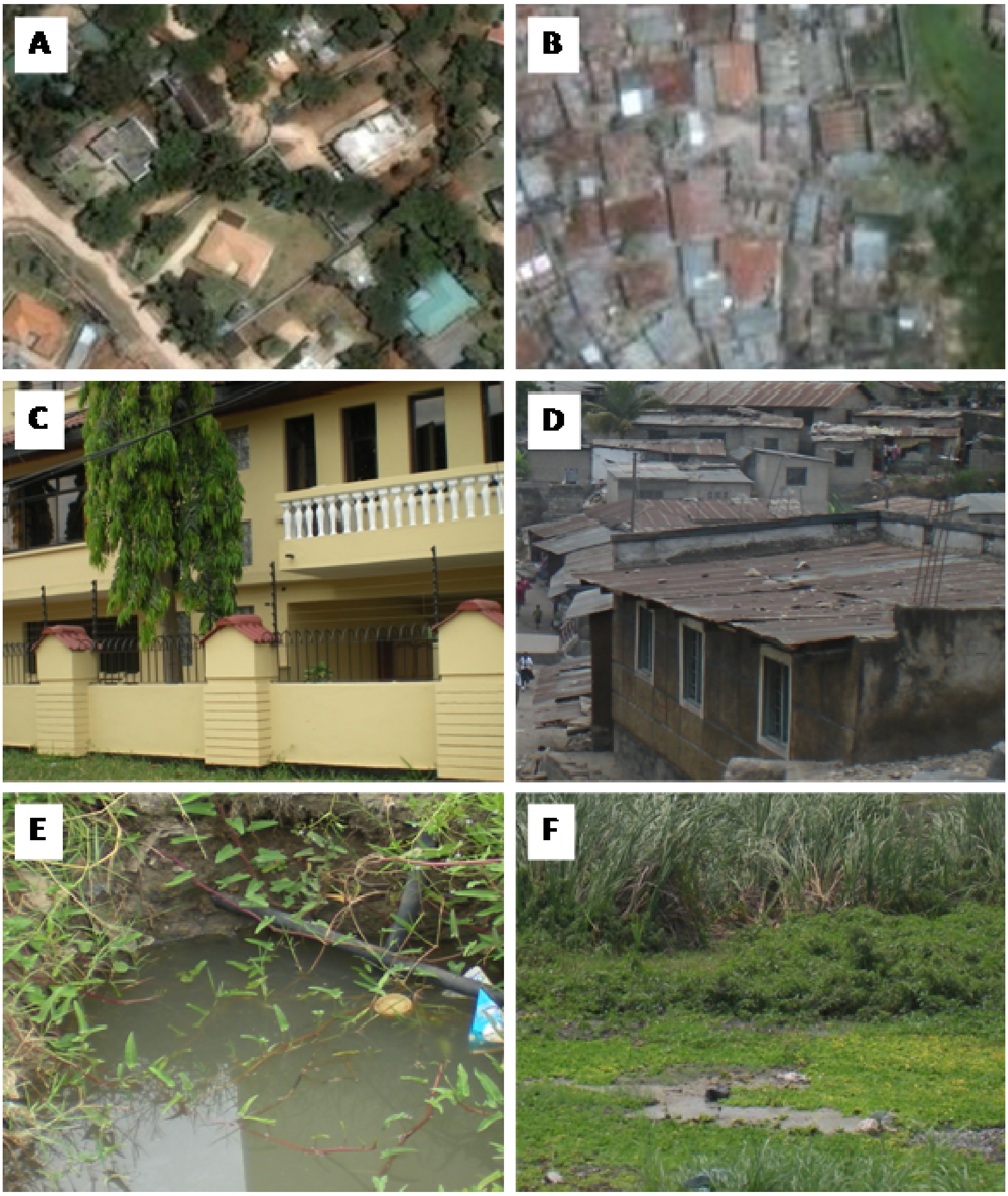

Figure 2.3.2 Aerial photos for planned **(A)** and unplanned **(B)** settlements of urban Dar es Salaam with ground-based photos of common features for each (**C** and **E** versus **D** and **F**, respectively). Planned settlements are characterized by relatively wealthy inhabitants, fences, tight security and restricted access but often contain suitable habitat within spacious plots (**E** was photgraphed within the compound seen in from the ground in **C** and from the air in **A**). Unplanned areas are characterized by dense settlement, scarce space for habitats, almost no fences and few but often prominent habitats which are readily accessible (**F** is located at the bottom of the valley pictured from the ground in **D** and from the air in **B)**.

The probability of a CORP detecting and recording a wet habitat was similar in larviciding and non-larviciding areas but was 84% less likely if he or she was unfamiliar with the area (Table 2.3.3). As mentioned earlier, the vast majority of the sites with which the CORPs were unfamiliar were within fenced plots. The covariance between these two variables (Pearson correlation, r^2 = 0.40, $P<0.001$) implies that the presence of fences around plots contributed to the lack of familiarity with plots among CORPs. Although excluded from the selected model presented in Table 2.3.3 because of this covariance, fenced plots, selected when familiarity was excluded, reduced the detection coverage by half (OR [95%CI] =0.49 [0.37-0.65], $P<0.001$).

Table 2.3.3 Factors associated with habitat detection coverage by CORPs.

Variable	% (n/N)	OR[95%CI]	P
Habitat category	NA	NA	0.053
Natural	66.4 (146/220)	1.00 [a]	NA
Artificial non-agricultural	66.1(1766/266)	0.60 [0.406,0.909]	0.015
Artificial agricultural	57.9 (44/76)	1.38 [0.607,3.143]	0.441
CORPs familiarity with plot	NA	NA	<0.001
No evidence of unfamiliarity	75.8(1788/235)	1.00 [a]	NA
Clear evidence of unfamiliarity	27.6 (168/608)	0.16 [0.130,0.203]	<0.001
Intervention status	NA	NA	0.978
Non-larviciding	72.4 (775/1070)	1.00 [a]	NA
Larviciding	62.3(1181/189)	0.99 [0.645,1.548]	0.997

The probability that a wet habitat was detected by the CORPs was modelled with a binary distribution and logit link function using Generalised Estimating Equations (GEE) treating intervention status, CORPs' unfamiliarity with the plots and habitat category as the potential predictors

[a] the reference group for the particular variable,

CI; confidence interval,

CORPs; community-owned resource persons

N; the number of wet habitats found during cross-sectional surveys

n; the number of wet habitats found by the CORPs during their routine habitat survey,

NA; Not applicable

OR; Odds ratios,

2.3.3 CORPs' detection of aquatic stage mosquitoes

Overall detection sensitivity of mosquito larvae was very low among CORPs. They found only 29 of 230 anopheline-positive habitats and 263 out of 830 culicine-positive habitats, corresponding to under-reporting rates of 87.4% and 68.4%, respectively. CORPs reported a higher proportion of larva-containing habitats in non-larviciding areas (anophelines: 27.6% (16/58) and culicines: 44.4 % (138/311)) than larviciding areas (anophelines: 7.6% (13/172) and culicines: 24.1% (125/519)). Detection sensitivity was twice as high for early instars 13.5% (28/207) than late instars 6.5% (10/155) of anopheline larvae (χ^2= 4.72, df=1, P=0.029). Detection sensitivity for early and late-stage culicine larvae did not differ (32.2%, (247/767) and 30.0%, (196/653) respectively (χ^2 = 0.787, df=1, P=0.375). Not only did most habitats (71.6%;

111/155) that contained late-stage anophelines during the investigator's survey occur in the larviciding areas, CORPs had reported this indicator of mosquito proliferation in only 3 of these cases (2.7%). Detection sensitivity of late stage Anopheles in non-larviciding areas was also very low (15.9%; 7/44) and did not differ significantly (P= 0.124) from larviciding areas.

Failures to detect mosquito larvae can be attributed to two distinct causes: (1) the aquatic habitat was not found and therefore no larval search took place or (2) the larvae were not detected during the inspection of that habitat. More than half of the anopheline (57.8%; 133/230) and culicine-positive (56.0%, 465/830) habitats were not recorded as wet by CORPs. In 60.9% and 95.7% of these non-reported anopheline and culicine-occupied habitats, respectively, the CORPs was either unfamiliar (anophelines; 45.1%, (60/133), culicines; 52.5%, (244/465)), the plot was fenced (anophelines; 45.9%, (61/133), culicines; 64.3%, (299/465)) or both (anophelines; 30.1%, (40/133), culicines; 21.1% (98/465)).

Anopheline larvae were identified by CORPs in only 29 of the 97 occupied habitats which they recorded as wet so overall detection sensitivity was 29.9%. More importantly they appeared unfamiliar with very few of both the anopheline-positive habitats which they reported as wet (5.2%, 5/97) and those which they did not (7.4%, 5/68). It therefore appears likely that not reporting larvae is due to insufficient dipping, examination or training in mosquito identification rather than not visiting the site. Notably, the detection sensitivity for culicine larvae in habitats that were reported as wet was much higher with almost three quarters of habitats containing these more obvious larvae being successfully identified (Table 2.3.4).

Table 2.3.4: Detection sensitivity of larval stages in different aquatic mosquito larval habitat types and categories by CORPs

		Anophelines			Culicines		
		Number of habitats found with larvae by[a]		Proportion detected by CORPs (%)	Number of habitats found with larvae by[a]		Proportion detected by CORPs (%)
		CORPs	Investigator		CORPs	Investigator	
Natural Habitats	Marsh/swampy areas	5	24	20.8	10	13	76.9
	Riverbeds	1	2	50.0	18	23	78.3
	Seepages	0	1	0.0	1	2	50.0
	Subtotal	*6*	*27*	*22.2*	*29*	*38*	*76.3*
Agricultural artificial habitats							
	Rice paddies	0	2	0.0	0	1	0.0
	Matuta	4	9	44.4	7	9	77.8
	Other agriculture	1	5	20.0	0	1	0.0
	Subtotal	*5*	*16*	*31.3*	*7*	*11*	*63.6*
Non-agricultural artificial habitats							
	Tyre tracks/puddles	1	14	7.1	15	21	71.4
	Drains	7	14	50.0	122	165	73.9
	Construction sites	9	24	37.5	68	91	74.7
	water storage containers	0	0	0.0	14	32	43.8
	Ponds	1	2	50.0	6	6	100.0
	Subtotal	*18*	*54*	*33.3*	*225*	*315*	*71.4*
	Total	**29**	**97**	**29.9**	**261**	**364**	**71.7**

[a]out of those habitats that were recorded as wet by the CORPs during their routine surveys

Larval detection sensitivity was different for different habitat types for anophelines (χ^2 =28.9, df=10, P=0.001) and culicines (χ^2=21.6, df=10, P=0.016). CORPs more readily detected anopheline larvae in larger, more obvious habitats like drains, riverbeds, ponds and *matuta* (Table 2.3.4). To enable fitting of a logistic model, these types had to be pooled into categories which had no significant effect. However, the probability of CORPs reporting larval anophelines occupying a habitat was drastically reduced if the habitat was located in an area where larviciding was ongoing (Table 2.3.5).

Late-stage *Anopheles* occupancy was reduced by over 70% in habitats in the intervention areas where the surveillance CORPs actually found and reported the wet habitats (Table 2.3.6). Note that no significant reduction of late-stage *Anopheles* occupancy was revealed for habitats in areas not covered by the intervention, regardless of whether the surveillance CORPs found them or not (Table 2.3.6).

Table 2.3.5. Factors associated with Anopheline and Culicine detection sensitivity in wet habitats reported by CORPs.

	Anophelines			Culicines		
Variable	% (n/N)	OR[95%CI]	P	% (n/N)	OR[95%CI]	P
Habitat category	**NA**	**NA**	**0.331**	**NA**	**NA**	**0.421**
Natural	22.2 (6/27)	1.00[NA][a]	NA[a]	76.3 (29/38)	1.00[NA][a]	NA[a]
Artificial agricultural	31.3 (5/16)	2.03[0.397-10.375]	0.395	63.6 (7/11)	0.72 [0.220-2.366]	0.590
Artificial non-agricultural	33.3(18/54)	2.34 [0.7607.231]	0.138	71.4(225/315)	1.39 [0.714-2.688]	0.336
Intervention status	**NA**	**NA**	**0.042**	**NA**	**NA**	**0.005**
Non- larviciding	40.0 (16/40)	1.00[NA][a]	NA[a]	80.6 (137/170)	1.00[NA][a]	NA[a]
larviciding	22.8 (13/57)	0.37 [0.142-0.965]	0.042	63.9 (124/194)	0.35 [0.167-0.722]	0.005

The probability of mosquito larvae detected by the CORPs modelled with a binary distribution and logit link function using Generalised Estimating Equations (GEE) treating intervention status and habitat category as the potential predictors.

[a]; reference group for particular variable

CI; confidence interval

CORPs; community-owned resource persons

N; the number of habitats that were reported to be wet by CORPs during routine habitat surveys and contained larvae during cross-sectional surveys

n; the number of habitats where CORPs found larvae during their routine habitat survey,

NA; Not applicable

Table 2.3.6. Impact of larviciding on late stage *Anopheles* larvae occupancy.

Variable	Proportion occupied % (n/N)	OR[95% CI]	P
Intervention status			
Non-larviciding	4.1 (44/1070)	1.00[a]	NA
Larviciding area	**5.9(111/1895)**	**2.32[2.19,6.14]**	**<0.004**
Intervention status x habitat found by CORP			
Found and reported by CORPs			
Non-larviciding	0.9 (7/782)	1.00[a]	NA
Larviciding area	**0.3 (3/1181)**	**0.22[0.147,0.34]**	**<0.001**
Not found or reported as dry habitats			
Non-larviciding area	4.7 (37/782)	1.00[a]	NA
Larviciding area	9.1(108/1181)	0.73[0.383,1.37]	0.325

The Odds of change of late *Anopheles* habitat occupancy subject to CORPs detection sensitivity of wet habitats and subsequent larvicide application as interacting terms modelled with a binary distribution and logit link function using Generalized Estimating Equations (GEE)
[a] reference group for a particular variable,
CI; confidence interval,
NA; Not applicable
n/N; the proportion of all habitats found to contain late stage *Anopheles* larvae by observations of the CORPs and the investigator.
OR; Odds ratios.

2.4 Discussion

The observation that CORP surveys at this stage of the UMCP's development had detected 66% of all aquatic habitats represents an improvement upon the 41% reported at the baseline surveys (Vanek *et al.* 2006) but nevertheless leaves significant room for improvement. The majority of the habitats that were not reported by CORPs, including most of those containing larvae, could be attributed to CORPs' unfamiliarity and, most importantly, to the presence of a fence. The latter is one of the most prominent features in urban settings, presumably resulting from growing security challenges. Limited access to the fenced plots reduces the chances of habitats being found, reported or treated, and undermines coverage of surveillance and vector control activities.

The fact that 75% of habitats with *Anopheles* mosquitoes that the CORPs did not find came primarily from three habitat types (puddles, marshes and construction sites), of which (30.3%) were behind fences, suggests considerable opportunity to achieve improvement through targeted training and increased emphasis upon these habitat types and plot characteristics (Figure 2.3.1). Notably, the CORPs more readily reported permanent sites such as ponds and riverbeds, rather than temporary puddles and rice fields where dipping might be more difficult and detecting larvae requires more effort.

Detection and consequent reporting of late-stage *Anopheles* larvae is considered an important indicator of successful larval control in programmatic settings because it is the most practical scalable indicator for imminent emergence of adult malaria vectors. It is important to note that CORPs detection sensitivity for this key indicator was low and clearly not adequate for monitoring and management of larviciding activities. The observation that CORPs in the larviciding areas detected proportionately fewer habitats with *Anopheles* larvae, compared with those in non-larviciding areas despite the higher number in the former and even when they had reported the habitats is particularly interesting. This may be attributed to lower larval density in treated habitats and/or reduced thoroughness among individual CORPs when searching habitats as they assume sites have been treated. Moreover, biases in the perspectives and CORP supervision practices of the ward supervisors with the competing interest of being responsible for larvicide application and surveillance, may account for these trends. The fact that larval occupancy in areas with larviciding was only reduced if habitats had been found by surveillance CORPs, suggests that if surveillance CORPs did not enter a plot or detect the habitat larviciding CORPs were also less likely to enter and treat them. Although a large number of CORPs were employed and a substantive internal quality control system formed an integral part of the routine protocols of the UMCP (Fillinger *et al*. 2008), it is striking that these did not detect these substantive problems in the front-line surveillance systems. These findings call for special emphasis upon directed strategies ensuring a more compliant operational team and engagement of the community in holding these teams accountable, as well as allowing area-wide access to plots and compounds.

2.5 Conclusion

The full true programmatic value of larviciding can only be established through evaluations of sustainable systems, which achieve much improved coverage relative to that reported here. The study has shown that unless improved access to fenced plots, and consequently detection of aquatic habitats and of larvae in them, is achieved, larviciding effectiveness will remain limited. To effectively implement larval control, we recommend that a less extensive surveillance system, focusing more on internal quality assurance based on accurate and timely reporting, be adopted. The labour-intensive and therefore expensive surveillance system implemented during the pilot phase of the UMCP (Fillinger *et al.* 2008) should be abandoned. Instead, it is recommended that rigorous external quality control of the internal process indicators used by implementers will be essential to make such monitoring systems meaningful and effective.

CHAPTER THREE

COMMUNITY-OWNED RESOURCE PERSONS FOR MALARIA VECTOR CONTROL: ENABLING FACTORS AND CHALLENGES IN AN OPERATIONAL PROGRAMME IN DAR ES SALAAM, TANZANIA

This paper has been published in

Human Resources for Health 2011, 9:21.

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3.0 Abstract

Background

Community participation in vector control and health services in general is of great interest to public health practitioners in developing countries, but remains complex and poorly understood. The Urban Malaria Control Program (UMCP) in Dar es Salaam, Tanzania, implements larval control of malaria vector mosquitoes. The UMCP delegates responsibility for routine mosquito control and surveillance to Community-Owned Resource Persons (CORPs), recruited from within local communities via the elected local government.

Methods

A mixed method, cross-sectional survey assessed the ability of CORPs to detect mosquito breeding sites and larvae, and investigated demographic characteristics of the CORPs, their reasons for participating in the UMCP, and their work performance. Detection coverage was estimated as the proportion of wet habitats found by the investigator which had been reported by CORP. Detection sensitivity was estimated as the proportion of wet habitats found by the CORPS which the investigator found to contain Anopheles larvae that were also reported to be occupied by the CORP.

Results

The CORPs themselves perceived their role as a professional rather than voluntary with participation being a *de facto* form of employment. Habitat detection coverage was lower among CORPs that were recruited through the program administrative staff, compared to CORPs recruited by local government officials or health committees (Odds Ratio = 0.660, 95% confidence interval = [0.438, 0.995], P = 0.047). Staff living within their areas of responsibility

had >70% higher detection sensitivity for both Anopheline (P= 0.016) and Culicine (P = 0.012) -positive habitats than those living outside.

Discussion and Conclusions

Improved employment conditions as well as involving the local health committees in recruiting individual program staff, communication and community engagement skills are required to optimize achieving effective community participation, particularly to improve access to fenced compounds. A simpler, more direct, less extensive community-based surveillance system in the hands of a few, less burdened, better paid and maintained program personnel may improve performance and data quality.

3.1 Background

Cities and large towns are regarded as some of the most favourable environments for sustainable public health development programs because of their relatively well educated, readily accessible populations with access to information, governance and social infrastructure (Knudsen and Slooff 1992, Trape *et al.* 1992). Nevertheless, many vertically-organized public health programs have had limited success because they fail to engage the community members in their planning and implementation (Service 1993a, Winch *et al.* 1992). It has consistently been elucidated that these obstacles are not due to a lack of medical, epidemiological or ecological technical competences, but rather a lack of knowledge on how to achieve the effective coverage through the widespread involvement of the communities in question (Oakley 1989a, Toledo *et al.* 2007). This has led many public health programs to adopt community participation as a fundamental basis for effectively and efficiently delivering interventions by overcoming resource limitations and maximizing intervention acceptability (Madan 1987, Parks *et al.* 2004, Rifkin *et al.* 1988). A number of studies have demonstrated that community involvement can improve intervention coverage, efficiency and effectiveness as well as promote equity and self-reliance (Heintze *et al.* 2007, WHO 1983, Winch *et al.* 1992). However, although there is general consensus about the benefits of community involvement on public health development, the strategies adopted are widely variable depending on the social-political context, institutional culture and the nature of community organization (Oakley 1989b, Zakus and Lysack 1998). It is thus possible, for the same strategy, to produce quite different effects; where there is a high level of social solidarity, communities will actively involve themselves, whereas where there is not the response may be more passive (Oakley 1989a, Toledo *et al.* 2007). While community mobilization is perceived as a potentially powerful, unexploited resource, and a means to appropriately and efficiently meet basic health needs (Mukabana *et al.* 2006, Rifkin *et al.* 1988, Zakus and Lysack 1998), comprehending and converting the rhetoric of community participation into reality remains a great challenge in public health (Bandesha and Litva 2005, Rifkin 1996, Toledo *et al.* 2007). This is especially true in the fragmented urban societies that are characterized by heterogeneous needs and mobile human populations.

The participation of communities in vector-borne disease control is context dependent (Espinol *et al.* 2004, Madan 1987, WHO 2006a, Winch *et al.* 1992). The degree of community involvement is determined by the type of disease targeted, available intervention options and the endemicity level (Madan 1987, Okanurak *et al.* 1992, Rifkin 1996, Toledo *et al.* 2007). The constituent activities of vector control can be implemented either intermittently, as with insecticide residual spraying (IRS) or insecticide treated bed nets (ITN) distribution campaigns, or routinely, as is the case for larvicide application or transmission surveillance (Fillinger *et al.* 2008, Killeen *et al.* 2006c, Mukabana *et al.* 2006, Townson *et al.* 2005). In either case, community engagement is essential as both interventions must be integrated into everyday activities and domestic or local environments. Furthermore, because vector control requires a comprehensive coverage, in addition to active daily participation, communities require administrative support. Thus strategies which combine extensive mobilization of community-based labour (Fillinger *et al.* 2008, Killeen *et al.* 2006c, Vanek *et al.* 2006) with vertical management structures embedded within pre-existing local government structures and public health systems may enable affordable, scalable and sustained community compliance while maintaining rigorous standards (Espinol *et al.* 2004).

A number of review papers have identified these key determinants of successful community participation in public health programs (Dunn 1983, Rifkin 1996, Rifkin *et al.* 1988). In the case of vector-control, meaningful, substantive collaboration between communities and experts at supporting institutions has successfully lead to the sustainable abatement of malaria and other vector-borne diseases (Knudsen and Slooff 1992, Mukabana *et al.* 2006, Okanurak *et al.* 1992, van den Berg and Knols 2006). Malaria control through larviciding or larval habitat reduction are intervention options with which considerable successes have been recorded both historically and very recently (Geissbuhler *et al.* 2009, Keiser *et al.* 2005, Killeen 2003, Killeen *et al.* 2002b, Shililu *et al.* 2003, Soper and Wilson 1943, Utzinger *et al.* 2001, Utzinger *et al.* 2002b, Watson 1953). It is notable that the most prominent recent large-scale (Fillinger *et al.* 2008) example relied upon extensive community involvement through vertical management systems to overcome the complex spatially variable mosquito larval ecology of relevant vector species and the resulting need for rigorous, labour-intensive foot searches for larval habitats (Fillinger *et al.* 2008, Killeen *et al.* 2002b, Killeen *et al.* 2006c). Such expert-community interactions often rely upon relatively few skilled personnel, carefully chosen from within local communities who shoulder the responsibility for implementation and communicating to the community at large so as to maximize compliance and effective coverage (Killeen *et al.* 2006c). It is widely accepted that well-chosen health personnel selected from within a community are more likely to gain community confidence (Oakley 1989a, Okanurak *et al.* 1992) and are therefore more efficient as behaviour change agents to achieve the desired impact (WHO 2006a). It is therefore essential for programme managers to consult the relevant communities prior to implementation in order to understand and anticipate local political forces, cultural and social interactions, as well as expectations (Winch *et al.* 1992, Zakus and Lysack 1998), as these will influence participation among, not only recruited individuals, but also the entire community. To understand the degree to which people will participate, it is important first to understand whether or not people will comply with the interventions. Moreover, if people do participate, it is important to understand how they interpret and value their involvement in the program over time (Gilson *et al.* 1989).

The Urban Malaria Control Program (UMCP) in Dar es Salaam, Tanzania has been initiated by the Dar es Salaam City Council as a pilot program to develop sustainable and affordable systems for larval control as part of routine municipal services (Castro *et al.* 2009, Castro *et al.* 2010, Chaki *et al.* 2009, Dongus *et al.* 2007, Fillinger *et al.* 2008, Geissbuhler *et al.* 2009, Govella *et al.* 2009, Mukabana *et al.* 2006, Sikulu *et al.* 2009, Vanek *et al.* 2006). The goal of the UMCP is to evaluate the effectiveness of a large-scale, community-based larval control program to reduce malaria transmission. The UMCP implements weekly application of microbial larvicides (*Bacillus thuringiensis* var. *israelensis (Bti)* and *B. sphaericus (Bs)* to all potential breeding habitats, and delegates responsibility for these routine mosquito control and surveillance to community members, referred to as Community-Owned Resource Persons (CORPs) (Fillinger *et al.* 2008).

Studies have revealed that even members of the most marginalized communities could be well protected from mosquito bites if given access to relevant knowledge, skills and resources (Onwujekwe *et al.* 2005, Schellenberg *et al.* 1999, Schellenberg *et al.* 2001, Service 1993a). The UMCP aims to address this capacity deficit by building partnerships between communities and malaria control experts. All UMCP activities are fully integrated into the decentralized administrative system in Dar es Salaam, in accordance with the local government structures introduced under the Local Government Act number 8 of 1982 as a response to adopting the Alma Atta Declaration (1978) (Anonymous 2001b), thus operating on all five administrative levels of the city.

The Health and Environmental Sanitation Committees at the ward and street levels are responsible for community participation in the health system, mobilizing resources from within communities, notably casual labour, and ensuring that hygienic conditions are maintained which includes monitoring the performance of individuals in health related projects (Anonymous 2001b). These committees typically consist of an average of eleven members. Despite their longstanding existence, little is known about how these committees function in practice or the extent of their impact on public health service delivery. One of the challenges faced by these committees is a lack of clarity in their terms of reference, particularly in relation to the extent and nature of their interaction with the community base.

This paper characterises the strengths and weaknesses of a recent effort to reinstate larval source management in Dar es Salaam implemented by community members through UMCP. The central aim of this study is to generate a better understanding of the role that the CORPs play within this programme, and the operational pre-requisites for these to contribute effectively in terms of representing the community voice, mobilizing the required resources and achieving the desired impact. By investigating the CORPs - their demographic characteristics, their reasons for participating in the UMCP, and their work performance – this study outlines how communities can become responsible for malaria control and, more broadly, how the audience of public health is realized within UMCP.

3.2 Methodology

3.2.1 Study Area

Dar es Salaam is Tanzania's biggest and economically most important city with a population which already exceeded 2.5 million inhabitants in 2002, and was estimated to reach 3.3 million in 2010, living within an administrative region of 1400 km^2 (Anonymous 2003b, UN 2010). The city is divided into three municipalities, namely Kinondoni, Temeke and Ilala, and these municipalities are further divided into a total of 72 wards. The study site comprised the 15 wards (5 per municipality) with 614,000 residents (Anonymous 2003b) included in the Dar es Salaam UMCP, covering an area of 56 km^2 (Fillinger *et al.* 2008, Geissbuhler *et al.* 2009, Geissbühler *et al.* 2007, Mukabana *et al.* 2006). All UMCP activities are coordinated by the City Medical Office of Health, and are fully integrated into the decentralized administrative system of Dar es Salaam. UMCP operates on all six administrative levels of the city: the city council, the 3 municipal councils it oversees, the 15 wards chosen from those municipalities, containing 67 neighbourhoods referred to as *mitaa* in Kiswahili (singular *mtaa*, meaning literally street), and more than 3000 housing clusters known as ten-cell-units (TCUs), each of which is subdivided into a set of plots corresponding largely to housing compounds. The main tasks of the 3 upper levels are programme management and supervision, whereas actual mosquito larval surveillance and control is organized at ward level and implemented at the level of TCUs and their constituent plots. In principle, a TCU is a cluster of 10 houses with an elected representative known as an *mjumbe*, but typically comprises between 20-100 houses in practice (Dongus *et al.* 2007). Between 2004 and 2009, the UMCP implemented regular surveillance of mosquito breeding habitats as a means to monitor effective coverage of aquatic habitats with microbial larvicides (Fillinger *et al.* 2008). Surveillance was done through a community-based (Vanek *et al.* 2006) but vertically managed delivery system (Fillinger *et al.* 2008). The cross-sectional surveys described here to evaluate routine surveillance activities were conducted between June 2007 and January 2008.

This study used a mixed method research design, combining qualitative and quantitative approaches (Creswell 2003, Tashakkori and Teddlie 2003).

3.2.2 Routine programmatic larval surveillance by community-based personnel

Community-Owned Resource Persons (CORPs) were recruited through local administrative leaders, particularly including Street Health Committees. They were remunerated at a rate of 3000 Tanzanian shillings (2008: US$ 2.45) per day through a casual labour system formulated by the municipal councils of Dar es Salaam for a variety of small-scale maintenance tasks such as road cleaning and garbage collection (Mukabana *et al.* 2006, Vanek *et al.* 2006). Over 90 larval surveillance CORPs were actively employed by the UMCP during the time of the survey with each assigned to a defined area of responsibility comprising a specific subset of TCUs within one neighbourhood. These subsets of TCUs were initially allocated based on local knowledge of habitat abundance, difficulty of terrain and geographic scale, and subsequently refined through detailed participatory mapping of the study area so that each CORP was responsible for an average area of approximately 0.6 km^2 (Dongus *et al.* 2007). All CORPs worked under the oversight of a single ward-level supervisor and followed a predefined schedule of TCUs which they were expected to survey on each day of the week. In wards where larviciding was taking place, the schedule of TCUs visited by the surveillance CORPs followed one day after that for the application of microbial larvicides by a separate set of larval control CORPs (Fillinger *et al.* 2008). By doing so, indicators of operational shortcoming, such as the presence of late-stage (3rd or 4th instar) mosquito larvae, could be reported and reacted to fast enough to prevent emergence of adult mosquitoes. This system was designed to enable routine mosquito habitat surveillance and larviciding, with the specific objective of allowing timely interpretation and reaction to entomologic monitoring data.

3.2.3 Qualitative preliminary assessment of community-based larval surveillance

Using structured participatory observation, one of the investigators (PPC) initially conducted three weeks of unscheduled guided walks with 23 of the surveillance CORPs. These CORPs were nominated by their respective ward supervisors after the investigator reported to their office unannounced in the morning. The investigator did not pre-inform the CORPs nor did he reveal his role and independent status at any time before or during the visit. Both the investigator and the chosen CORPs would leave the ward office and survey TCUs that the CORPs were expected to survey according to their normal predefined schedule for that particular day (Fillinger *et al.* 2008), returning later to report to the ward supervisor. At this stage, the survey was led by the CORPs and the investigator followed passively, observing and recording how CORPs conducted their routine larval habitat surveillance and prepared their daily reports for submission to the ward supervisor. Specifically, the following six key questions guided observation on whether individuals adhered to the set standard operating procedures (Fillinger *et al.* 2008): (1) Did

CORPs follow their schedule correctly? (2) Were all TCUs and plots visited? (3) Were fenced compounds entered, and if not, why not? (4) How were habitats recorded? (5) How were habitats searched for larvae? (6) How did CORPs interact with residents? In cases of observed shortcomings in the operational practices of the CORPs, or any additional opportunities for improved implementation of their duties, the investigator provided the CORPs with informal advice. This approach was intended to maintain an open, non-authoritative relationship of the investigator with the CORPs, allowing the investigator to observe and understand the operational challenges faced by the CORPs and the program as a whole. Informal appraisal of these observations was used to design a quantitative survey described as follows (Chaki *et al.* 2009).

3.2.4 Quantitative cross-sectional evaluation of community-based larval surveillance

A total of 173 TCUs from neighbourhoods distributed across all 15 wards were randomly selected from the list of TCUs in the UMCP study area. A total of 64 CORPs were responsible for these selected TCUs. The investigator accompanied the relevant CORPs during the survey through each TCU one day after their scheduled routine surveillance of that TCU and implemented his own larval habitat surveys following the standard operating procedures (Fillinger *et al.* 2008). At this stage, the visits remained unannounced but the investigator's role was revealed. The investigator conducted a comprehensive search of each plot for potential breeding habitats and then searched each of those for mosquito larvae following standard operating procedures (Fillinger *et al.* 2008). First, the larval survey data sheet filled by the CORP on the previous day was examined. Then the presence of every reported wet habitat was verified, and each one was re-examined for the presence of larvae or pupae. Then any additional habitats that had not been detected by the surveillance CORPs were identified and examined for the presence of larvae. All data for the follow-up survey of the investigator recorded using standardized forms adapted from those provided to the larval surveillance CORPs (Chaki *et al.* 2009, Fillinger *et al.* 2008). The proportion of wet habitats reported by CORPs was compared to the total number of all potential habitats by the investigator to establish the detection coverage, whereas detection sensitivity was established by comparing the proportion of habitats which contained larvae that were reported by the CORP with that reported from the investigator's survey.

Additional information was collected regarding the presence or absence of a fence around a plot and whether or not a particular TCU was targeted with larvicide application at the time that it was surveyed. Lastly, records were taken regarding evidence of lack of familiarity of a CORP with the specific TCU and plot. Unfamiliarity was assumed if the CORP was not readily able to find his or her way around the TCU or plot, when plot boundaries could not be clearly defined, or when residents of the plot were unable to recognise him/her as a regular visitor to the area (Chaki *et al.* 2009). At the end of each visit, a structured questionnaire was administered to collect data regarding the individual characteristics of the CORPs including gender, age, place of residence and recruitment history (Appendix 2).

3.2.5 Data Analysis

The results from the participant observation during the guided field walks with the CORPs were subject to content analysis to identify the main themes. Our interpretation of themes articulated in interviews is supported by a comparative ethnographic research on community participation in larval control projects in The Gambia (Kelly *et al.* 2010). The fully pre-coded numeric forms with interview responses were entered and analyzed using SPSS 16.0. Generalized estimating equations were fitted to determine the influence of the various factors upon the proportion of wet habitats (detection coverage) reported by CORPs and the proportion of habitats which contained larvae that were reported to be occupied by the CORP (detection sensitivity). The factors included were clear knowledge of project goal, frequency of field visits by supervisor, where the individual CORPs lived, relationship with the residents, by whom individuals were recruited, and time spent to get to the field. While all observed habitats were included in the model fits to assess detection coverage, only those found by the CORPs and reported to contain larvae by the investigator were considered in the denominator of the models to assess detection sensitivity. The detection of the wet habitat or its larval occupancy by the CORP was each treated as the binary outcome variable which was fitted to a binomial distribution with a logit link function. CORP identity was treated as the subject variable and an exchangeable correlation matrix chosen for the repeated measurements which were distinguished by habitat identity as the within-subject variable.

3.3 Findings

3.3.1 CORPs' demographic characteristics

Overall, 64 CORPs, of whom 36 were male and 28 female, were surveyed. All of the respondents initially received work-related training at recruitment, organized by the program staff. This primarily involved field/practical training to develop basic skills for the identification of different types of breeding habitats, aquatic-stage mosquitoes and operational skills such as community engagement and obtaining access to private plots. In addition to field training, 83%

(53) of the interviewed individuals had also attended seminars, 61% (39) had received relevant reading materials and 58% (37) received both. Twenty six (41%) respondents had only attended primary education with the remaining majority having secondary education. Approximately half (52%, 33) of these CORPs were between 20 and 29 years of age while 28% (18) were between 30 and 39 and the remaining 20% (13) were 40 and above. Individuals' age correlated positively with the length of time they had spent working for UMCP ($r^2 = 0.327$, $P = 0.008$). A third (31%, 20) of the respondents had been with the program for one year or less. Four fifths (81%; 52) of the respondents stated they had no other source of income. All of those with another source of income (19%, 12) were involved mainly in petty trading. 34% (22) of interviewed CORPs reported to have formally or socially recognized positions within their respective Community Health and Environmental Committees at either the ward or neighborhood level. 9% (6) of those interviewed had previously worked in similar vector control programmes in the past (Castro *et al.* 2004). The majority (59%; 38) of the interviewed CORPs reported spending between six and seven hours in the field each day while 22% (14) spent between eight and nine hours a day and 19% (12) spent four to five hours in the field.

The initial quantitative evaluation results showed a substantial improvement in the detection and correct identification of breeding habitats (Chaki *et al.* 2009) compared with previous prototype systems (Vanek *et al.* 2006). The majority of the CORPs exhibited basic competence in identifying and reporting malaria vector breeding sites: almost three thousand aquatic habitats were recorded during the survey, of which 66.2% (1963) were detected by the 64 CORPs (Chaki *et al.* 2009), implying that the majority of them had at least a basic understanding of how to identify mosquito breeding sites. As previously described, the observed detection sensitivity for mosquito larvae was consistently low (Chaki *et al.* 2009).

3.3.2 Contextual determinants of detection coverage identified through the guided walks

Initial observations and analysis of the interview data from the guided walks with the individual CORPs and supervisors suggested that, despite their enthusiasm for the work the community-based staff wished to be consulted more in decisions made concerning the working conditions of the program. The major concern expressed was the unfair distribution in work between the CORPs and other UMCP staff at program management levels (Table 3.3.1). CORPs cited a number of incidents that had happened to some of their colleagues or themselves, which they considered illustrative of the lack of understanding of the conditions of work by the higher operational levels within UMCP administrative hierarchy. During the discussion one respondent emphasized in particular, the failure of administrators to take into account the daily needs of CORPs and the consequences this had for their wellbeing (Table 3.3.1).

Most CORPs explained that though they are regarded as volunteers working on a part time basis, the work is so demanding and exhausting that it takes up most of their day and they become too tired to do anything else that could contribute to their livelihood (Table 3.3.1). There was a high degree of job dissatisfaction tied to the amount of remuneration they received per working day, which was not perceived as being proportional to the working hours and effort invested. A recurring challenge to the comprehensive habitat surveillance and achieving sufficient coverage was gaining access to fenced compounds (Chaki *et al.* 2009): One CORP complained that supervisors, while sympathetic, were also not capable of crossing these socio-economic barriers.

Most interviewee continually emphasized how these drawn out social negotiations exacerbated the workload:

Across the interviews, the most salient enabling factor was the CORPs' ability to relate positively with the residents in those areas. Being able to relate to home-owners was generally associated with having worked previously with the Community Health Committees. A third of the CORPs (34%, 22) and their supervisors repeatedly mentioned that having a recognized formal role within these respective bodies made their work easier by enabling effective communication with the residents. This was especially true in relation to accessing enclosed, often-guarded compounds and removing abandoned container-type habitats, such as tires, within those plots.

Much of this point to limited access, motivation among staff, and compliance among residents with project activities, and partly explain how and why individual CORPs were recruited into UMCP. The fact that almost half of all aquatic habitats were located within fenced plots (Chaki *et al.* 2009) makes access an even more serious obstacle to intervention coverage. One fifth of all aquatic habitats were recorded in plots with which CORPs clearly appeared unfamiliar and over 90% of these were located behind fences (Chaki *et al.* 2009).

It cannot be fully ascertained that the role of the investigator was successfully withheld from the CORPs in all cases and their supervisors probably represent the most likely source of such knowledge. This may have influenced their working practices while with the investigator so the practices reported here may well be positively biased to some degree.

Table 3.3.1: Assorted responses from the interviewees illustrating the main contextual factors influencing their routine performance

	CORPs	**Ward & Municipal Supervisors**
Community Relations	*I encounter problems entering some of these houses. For example, here lives a white man, he keeps snakes and dogs. I have not been able to go in because the security guards had advised me not to, even though I can see from here that there is a swimming pool and tires but I could not do anything. Maybe the project leaders should assist us in educating these people because I have shared this with my supervisor but she could not help me.* *Sometimes you get to a fenced house so you knock at the gate. First comes the house girl and she asks what you want. You explain that you need to go inside to look for breeding places and she might tell you just wait. So you stand there waiting for minutes. Then a boy comes and he asks you to explain again. If you are lucky they will let you in, otherwise you will be told the house owners are not here so come later or tomorrow. This takes a lot of time, so sometimes we do not bother to go there.*	*For me as a supervisor, I find it easy to work here because I belong to this ward and I am a member of the environmental committee, so I have no problem working with people. (Ward Supervisor)* *Some of the CORPs they have had previous experiences, with UNICEF or other projects, so they know how to approach people and inform them. Others are inexperienced and the moment they run into problems, they stop the work and give up (Municipal Coordinator)*
Views on UMCP Work	*We are responsible for the project – we are working all day out in the field. The supervisors are not out here in the field and they receive a far greater amount…if we were valued as part of the project, like the supervisors, it would make the job easier for us.* *The work I do is hard, but it is a good project... I have come to know the community members. We are all hoping there will be more opportunities and we will continue to do this work.*	*The CORPs who work with us are very good, the problem is not many stay with us for long – it is very difficult work, they go and the training is lost. We need to be careful in our selection, ones that have experience and will have an easier time, it is no good when they come and go (Municipal Coordinator).* *This project has worked best where the community is most involved. If we give power to the Mtaa leaders to select, coordinate and fund larval control it will be sustainable. (Municipal Coordinator)*
Motivation to Participate	*I feel like this is the only way out for me, because at least I get assured of being paid at the end of the month…* *I need at least some time off. I have to rest for at least a week and, at the same time, use that opportunity to meet my relatives. But the way things are, if I go on leave for just a day I will not be paid, and I do not want that to happen because I need that money.*	*This has been a good project and has made a large impact on the community. We are all thinking it should be continued, though we cannot be assured what will happen in the next years. We are now all working well together, we can only hope that the project is taken up permanently (Ward Supervisor).*
Working Conditions	*I remember there was one CORP, who was working here, but he got sick and so for days he could not go to work. He was very sick but the project did nothing to help him until his relatives came to take him to their home. He unfortunately had to go for treatment. So even if you get sick, you still have to find a way to at least get to work so that you can get the money for that day, because we need money and the project has no budget for treatment.*	*I think being a supervisor is a tough job, because you not only have to look at your own work, but also make sure that even those under you are doing the right job There is so much to be done because I have to split my time between going to the field to see what they are doing and check the reports that I receive because I do not trust some of them. Now that we are applying the larvicide, it is even tougher because I have to check on the two teams and yet if you look at what we are being paid it is very little unlike our fellow inspectors [municipal level]. They do little but they get paid twice what we get. (Ward Supervisor).*

3.3.3 Determinants of aquatic habitat detection coverage

The aquatic habitat detection coverage levels varied significantly between wards ($P<0.001$), probably reflecting individual geographic variation and ward-level variation in the quality of supervision (Chaki *et al.* 2009). The probability of detecting and recording breeding habitats by CORPs was significantly reduced if the CORP could not clearly explain the overall goal and activities of the programme (Table 3.3.2). Individuals' clarity of understanding of the programs' objectives positively correlated with the time length they have worked for the program (Pearson correlation, $r^2 = 0.472$, $P< 0.001$). This implies that, as individuals spend longer times with the programme, they become more competent, knowledgeable and accurate advocates for the project within their communities and areas of responsibility. However, staff turnover was a major problem within UMCP as almost one third (31.2%, 20/64) of the CORPs interviewed reported to have been working with the program for less than a year. The implied high turnover rate is obviously problematic for a labour-intensive program relying on experienced personnel to realize effective implementation and community engagement.

Larger areas of responsibility probably increased the amount of time that individual CORPs spent to get to work and search for breeding habitats (Table 3.3.2). Consequently, there was a 47.8% reduction in habitat detection coverage among individual CORPs who reported spending an average of half an hour or more to get to their scheduled TCUs (Table 3.3.2). However, it is less clear why CORPs that reported to be spending between a quarter to half an hour appear to achieve almost two fold higher detection coverage. We attribute this observation to either a spurious model fit or to other unknown determinants or covariates of detection coverage and cannot comment further.

Habitat detection coverage differed significantly among CORPs depending on who had recruited them into the program: Detection coverage was a one-third lower among individuals that had been recruited directly through programme staff rather than through local community leaders (Table 3.3.2).

Furthermore, the reported degree of support provided by residents to interviewed CORPs demonstrated strong influence on the observed habitat detection coverage. Though less uniformly defined, coverage was 63% higher in areas where the CORP reported residents were reasonably rather than very supportive of the program. Based on our own observations in the field, we interpret this pattern to imply that CORPs' reports of community supportiveness reflect a measure of honesty among program staff with answers of "very supportive" probably being exaggerated in most cases (Table 3.3.2).

Table 3.3.2: Factors associated with mosquito larval habitat detection coverage

Interviewee response	*Proportion of respondent CORPs %(a/64)*	*Proportion of habitats detected by CORPs %(n/N)*	OR [95%CI]	P
Clear knowledge of project goal and advocacy level	*NA*	*NA*	NA	0.002
Complete	*59 (38)*	*70.0 (1281/1829)*	1.00[b]	NA
Incomplete	*41 (26)*	*59.4 (675/1136)*	0.596 [0.403,0.880]	0.009
Who individuals were recruited by	*NA*	*NA*	NA	0.004
Community local leaders	*79 (50)*	*68.4 (1625/2375)*	1.00[b]	NA
Project administrative staff	*22 (14)*	*56.1 (331/590)*	0.660 [0.438,0.995]	0.047
Perceived relationship with the residents	*NA*	*NA*	NA	0.028
Very supportive	*64 (41)*	*62.7 (1068/1703)*	1.00[b]	NA
Reasonably supportive	*36 (23)*	*70.4 (888/1262)*	1.627 [1.053,2.515]	0.028
Time spent to get to the field	*NA*	*NA*	NA	0.011
Less than or equal to quarter an hour	*73 (47)*	*65.0 (1477/2273)*	1.00[b]	NA
Above quarter but less than half an hour	*17 (11)*	*78.5 (350/446)*	1.943 [0.965,3.912]	0.063
More than half an hour to one hour	*9 (6)*	*52.4 (129/246)*	0.522 [0.288,0.946]	0.032

The probability that a wet habitat was detected by the CORPs was modelled with a binary distribution and logit link function using Generalised Estimating Equations (GEE) treating clarity and advocacy level, recruiting level, relationship with the residents and the time individuals used to get to the field as potential predictors (exluded factors included where individuals lived (P=0.997) and frequency of field visits by supervisor (P=0.892))

[a];number of CORPs

CI;confidence interval

OR;Odds ratio

[b]; the reference group for the particular variable

N;the number of wet habitats found during the cross-sectional surveys

n;the number of wet habitats found by CORPs during their routine habitat survey,

NA;Not applicable

3.3.4 Determinants of larval-stage mosquito detection sensitivity

As previously described (Chaki *et al.* 2009), overall detection sensitivity of larvae was very low among the surveyed CORPs (Table 3.3.3). As was the case for habitat detection coverage, and presumably for the same reasons, larval detection sensitivity was considerably better among CORPs reporting that residents were reasonably rather than very supportive (Table 3.3.3). Furthermore, detection sensitivity for both Anophelines and Culicines was dramatically lower among CORPs that were not living within their areas of responsibility (Table 3.3.3) regardless of whether they lived within the same or outside wards. The reductions in Culicine detection sensitivity were statistically significant and those for Anophelines approached significance (Table 3.3.3). However, when the two groups of CORPs living outside areas of responsibility were pooled together a statistically significant reduced detection sensitivity for Anophelines (OR [95%CI] = 0.25 [0.084, 0.774], P = 0.016] and Culicines (OR [95%CI] = 0.26 [0.092, 0.740], P = 0.012) was recorded among CORPs in this group compared to those living within areas of responsibility. More frequent field supervision than the standard recommendation of once per week was associated with reduced culicine detection sensitivity among respective CORPs, presumably because these were known by the supervisor to be poor performers (Table 3.3.3). Correspondingly, less frequent field visits than the recommended once per week by the supervisor appear to be associated with more competent CORPs with a threefold increase in culicine detection sensitivity (Table 3.3.3). Although no statistically significant influence on anophelines detection was apparent, presumably because this was generally very low so the number of observations was also low, there was over twofold increase in detection sensitivity among the less frequently visited CORPs (Table 3.3.3).

Table 3.3.3: Factors associated with Anopheline and Culicine detection sensitivity by individual CORPs

Interviewee response	Proportion of respondent CORPs[a]	Proportion of Anopheline-positive habitats found by CORPs[b]			Proportion of culicine-positive habitats found by CORPs[c]		
	%	**%(n/N)**	**OR[95%CI]**	**P**	**%(n/N)**	**OR[95%CI]**	**P**
Relationship with the residents	**NA**	**NA**	**NA**	**<0.001**	**NA**	**NA**	**0.041**
Very supportive	64 (41)	10.0 (2/20)	1.00[c]	NA	74.1 (209/282)	1.00[c]	NA
Reasonably supportive	36 (23)	36.4 (28/77)	4.26[2.111,8.597]	<0.001	60.0 (51/85)	2.77[1.043,7.342]	0.041
Frequency of field visits by supervisor	**NA**	**NA**	**NA**	**0.400**	**NA**	**NA**	**0.016**
More than once a week	16 (10)	17.4 (4/23)	1.02[0.208,5.036]	0.977	44.2 (19/43)	0.55[0.217,1.377]	0.200
Once a week	61 (39)	36.4 (20/55)	1.00[c]	NA	70.7 (159/225)	1.00[c]	NA
Less than once a week	23 (15)	31.6 (6/19)	2.54[0.580,11.082]	0.216	82.8 (82/99)	3.24[1.016,10.312]	0.047
Where the individual CORPs lived	**NA**	**NA**	**NA**	**0,098**	**NA**	**NA**	**0.013**
Within area of responsibility	44 (28)	35.7 (15/42)	1.00[c]	NA	77.3 (126/163)	1.00[c]	NA
Within ward of responsibility	31 (20)	31.0 (9/29)	0.30[0.079,1.129]	0.075	71.5 (88/123)	0.24[0.078,0.765]	0.016
Outside ward	25 (16)	23.1 (6/26)	0.24[0.037,1.471]	0.122	58.0 (47/81)	0.21[0.057,0.740]	0.015

[a] proportion of respondents out of the overall 64 CORPs interviewed

[b] out of those habitats that were recorded as wet by the CORPs during their routine surveys

The probability of mosquito larvae detected by the CORPs modeled with a binary distribution and logit link function using Generalized Estimating Equations (GEE) excluding time spent to get to the field (P= 0.608), Who individuals were recruited by (P=0.521) and clear knowledge of project goal (P=0.654).

[c;]Reference group for particular variable, CI; confidence interval, CORPs; Community-owned resource persons

N; the number of habitats that were reported wet by CORPs during routine habitat surveys and contained larvae during the cross-sectional surveys

n; the number of habitats where CORPs found larvae during their routine habitat surveys,

NA; Not applicable

3.4 Discussion

This study used both qualitative and quantitative methods to explore the perspectives of CORPs and their respective supervisors about the management of UMCP, particularly employment conditions and community engagement practices. The results suggest that there are important differences in perceptions of participation and its associated intervention effectiveness, between the program management levels and CORPs.

Although the UMCP actively involved and depended on CORPs in the routine implementation of breeding habitat surveillance, there appeared to be significant limitations in the employment system with regard to how these human resources were identified, mobilized and maintained. The fact that individual’s ability to detect breeding habitats was reduced when program staff instead of local leaders recruited CORPs emphasizes the need to enforce the policy of local government ownership and control of the recruitment process. It has been demonstrated clearly that most appropriate and effective personnel for implementing community-based interventions are resident community representatives carefully chosen through the local government leadership. The results confirm the findings of others (Oakley 1989a, Okanurak *et al.* 1992) regarding the importance of engaging the resident communities in health development programs.

Overall these results outline a picture of mediocre performance and imply an urgent need for equipping these community personnel with skills to effectively communicate and engage the whole community (Dongus *et al.* 2010). Within the UMCP surveillance system at that particular time, more priority was placed on technical larval surveillance and larvicide application skills with inadequate emphasis on the capacity to interact and communicate. It is therefore important that while training needs to focus on improving technical skills, especially the ability to detect and classify larvae (Chaki *et al.* 2009), increased emphasis should also be placed on improving individuals' communication skills to enable them to interact more extensively and effectively with the rest of the community. In other words, sensitization has to go beyond mere transfer of knowledge and seek to optimize community support and engagement for sustainable program effectiveness. This confirms the findings from another study (Dongus *et al.* 2010) conducted within the UMCP which focused on resilience building processes and emphasized the vital role of improved communication among stakeholder communities and the program staff for effective malaria vector control.

A prerequisite for mosquito control programs focusing on larviciding in urban areas is having access to all locations where mosquito breeding takes place. This includes fenced plots and other areas with restricted access for the public, and thus requires substantive and open collaboration between stakeholders. Such collaboration could be achieved by enhancing access to knowledge and information among the various stakeholders at all levels. The fact that habitat detection coverage was higher among CORPs recruited by the local government leadership and the detection sensitivity was generally lower among CORPs residing in areas away from their areas of responsibility suggests one very clear recommendation: Community based personnel should be recruited through the existing community structures such as the community health committees and work only where they live. Furthermore, the recruitment process of the community personnel needs to critically consider the heterogeneity and mobility of the human population in the specified environment, and the socioeconomic and political influences that are likely to shape the level and extent of community participation. Moreover, existing and influential local committees need to be fully integrated as these are likely to dictate levels of community involvement. It cannot be reasonably expected of city or municipal level staff to fully understand or manage such complex and subtle issues at the fine scales at which implementation occurs, so these tasks must be consistently devolved to the local level.

Moreover, perhaps less extensive but better controlled community-based surveillance with fewer supervisors who are better paid, motivated and retained could improve the quality of data obtained through such community-based surveillance systems. This view can be supported by the supervisor's opinions as expressed in the quotes above of the results section. Following this survey, the UMCP has since been restructured accordingly, with habitat surveillance reduced to a sample of about 6% of TCUs each week. Furthermore, this responsibility is now exclusively allocated to better paid ward supervisors who are no longer overburdened with excessive data collation from numerous CORPs. They are now unambiguously responsible for implementing surveillance in the field themselves in an average of five TCUs per week which are randomly chosen and other five which they choose at their own discretion. It remains to be proven that such changes will yield improvements in these performance indicators and, ultimately, increased epidemiological impact. The results of this study provide a baseline and outline useful indicators with which such systems interventions can be assessed and understood.

3.5 Conclusion

Resident larval surveillance field staffs recruited from within the intervention areas and by the respective local governments instead of the programme management, appears to be most suitable for achieving high breeding site detection coverage and larvae detection sensitivity. Moreover, local governments, and resident CORPs appear ideal for mobilizing the essential resources and the necessary community support for establishing sustainable malaria vector control systems. Improved employment conditions, communication and community engagement strategies as well as engaging the local health committees in recruiting individual program staff are crucial factors for achieving effective community participation and consequently epidemiological impact.

CHAPTER FOUR

AN AFFORDABLE, QUALITY-ASSURED COMMUNITY-BASED SYSTEM FOR ENTOMOLOGICAL SURVEILLANCE OF VECTOR MOSQUITOES THAT REFLECTS HUMAN MALARIA INFECTION RISK PATTERNS

This paper has been submitted for publication

to the *Malaria Journal*.2012

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4.0 Abstract

Background

Despite increasing coverage with indoor residual spraying (IRS) and long-lasting insecticidal nets (LLINs), ongoing malaria transmission by outdoor-biting mosquitoes, in particular necessitates complimentary vector control strategies such as larval source management. In addition to that correspondingly sensitive and scalable entomological surveillance tools are required to monitor the lower levels of transmission that now persist in many parts of the tropics. The Urban Malaria Control Program (UMCP) in Dar es Salaam, Tanzania therefore implements a large-scale larviciding program supported by a community-based (CB) system for trapping adult mosquito densities to monitor program performance on a weekly basis.

Methodology

An intensive and extensive CB system for routine, longitudinal, programmatic surveillance of malaria vectors and other mosquitoes using the Ifakara Tent Trap (ITT) was developed in Urban Dar es Salaam, Tanzania and evaluated in comparison with quality assurance (QA) surveys using either ITT or human landing catches (HLC). Thirty one community-based mosquito catchers, who slept in an ITT, collected host-seeking mosquitoes at a total of 615 locations, comprising 31 clusters of approximately 20 locations for which a specific catcher was responsible. Involvement of a central vertical management team in the CB surveys was restricted to laboratory processing of mosquito samples and closely supervised QA surveys consisting of 15 HLC and 20 ITT-C tent trap catches per week in randomly selected subsamples of the CB survey locations. A cross-sectional survey of malaria parasite prevalence was conducted using rapid diagnostic tests (RDT) from each housing compound where the CB mosquito surveys were conducted.

Results:

Community-based ITT-C had much lower sensitivity per person-night of sampling than HLC (Relative Rate (RR) [95% Confidence Interval (CI)] = 0.079 [0.051, 0.121], P < 0.001 for *Anopheles gambiae s.l.* and 0.153 [0.137, 0.171], P < 0.001 for Culicines) but did only moderately differ from QA surveys with the same trap (0.536 [0.406,0.617], P=0.001 and 0.747 [0.677,0.824], P<0.001, (for *Anopheles gambiae* or Culex respectively). Despite the poor sensetivity of the ITT per night of sampling, when CB-ITT was compared with QA-HLC, it proved at least comparably sensitive in absolute terms (171 versus 169 primary vectors caught) and cost-effective (153US$ versus 187US$ per *An. gambiae* caught) because it allowed more more spatially extensive and temporally intensive sampling (4284 versus 335 trap nights distributed over 615 versus 240 locations with a mean number of samples per year of 143 versus 141). Despite the very low vectors densities (Annual estimate of about 170 *An gambiae* bites per year), CB-ITT estimates of biting rates correlated significantly with HLC based estimates (P<0.001) and was the only epidemiologically relevant entomological predictor of parasite infection risk (Odds Ratio [95% CI] = 4.43[3.027,7. 454] per *Anopheles gambiae* or *An. funestus* bite per night, P =0.0373).

Discussion and Conclusion

The CB trapping approach described could be improved with more sensitive traps but already offers a practical, safe and affordable system for routine programmatic mosquito surveillance and could be applied on larger scales by distributing the clusters across entire countries and adapting the sample submission and quality assurance procedures accordingly.

4.1 Background

Recent successful malaria control efforts have overwhelmingly relied on proven intra-domicilliary vector control interventions, such as long-lasting insecticidal nets (LLINs) (Bhattarai *et al.* 2007, Ceesay *et al.* 2008, D'Acremont *et al.* 2010, Fegan *et al.* 2007, Hay *et al.* 2009, Noor *et al.* 2008, Nyarango *et al.* 2006, O'Meara *et al.* 2010, O'Meara *et al.* 2008, Okiro *et al.* 2007, Phillips-Howard *et al.* 2003b) and indoor residual spraying (IRS) (Kleinschmidt *et al.* 2009a, Kleinschmidt *et al.* 2009b, Sharp *et al.* 2007a, Sharp *et al.* 2007b), that kill mosquitoes feeding or resting inside houses (Ferguson *et al.* 2010). Although these indoor interventions have proven potential to reduce *Plasmodium falciparum* transmission and associated disease burden, neither of these alone is sufficient to even approach elimination in most endemic areas (Bugoro *et al.*, Griffin *et al.* 2010, Gubler 1998, Killeen and Smith 2007, Killeen *et al.* 2007, Russell *et al.* 2010) because of persistent vector populations that rest outdoors (exophilic), feed outdoors (exophagic), or feed on animals (zoophagic) (Bugoro *et al.* 2011, Griffin *et al.* 2010, Reddy *et al.* 2011, Russell *et al.* 2011a). National Malaria Control Programs (NMCPs) presently face the challenge of monitoring declining transmission levels mediated by dramatically altered residual vectorial systems with greater sensitivity than ever before. This task will become more challenging as universal coverage with LLINs and IRS is achieved, sustained and even supplemented with additional complementary measures (Ferguson *et al.* 2010, Griffin *et al.* 2010). Such residual transmission is often persistent, self-sustaining and quite localized, and may be perennial in some hotspots (Bejon *et al.* 2010, Bousema *et al.* 2010, Cohen *et al.* 2010, Giglioli 1963, Malakooti *et al.* 1998, Zucker 1996), necessitating the implementation of sensitive, longitudinal and extensive vector surveys may be required. Traditional entomologic-monitoring tools have been designed and evaluated for research purposes, primarily in the holoendemic settings where malaria research has traditionally been based. These tools may therefore be impractical to apply on scales large enough to detect and target such hotspots of low but persistent transmission.

Most malaria-endemic developing countries are challenged with a persistent shortage of expertise relating to vector control, and indeed to health systems generally (Breman *et al.* 2004, Najera 1989, Najera 2001, San Martín and Brathwaite-Dick 2006, Trigg and Kondrachine 1998). These deficiencies have resulted in weak monitoring, evaluation and management of vector-borne diseases, including malaria. Even if large numbers of expert personnel were available to staff large, predominantly vertical, vector surveillance programmes, the cost of sustaining such human resources would be prohibitive in most African countries (Killeen *et al.* 2006c, Mukabana *et al.* 2006, Townson *et al.* 2005). Thinking among public health practitioners has therefore shifted to consider devolving the responsibility for vector surveillance and also control to members of the respective communities (Mukabana *et al.* 2006, Toledo *et al.* 2007, Townson *et al.* 2005, WHO 2004). This is envisaged to have two advantages: First, this strategy is anticipated to be affordable and can therefore be sustained indefinitely on large scales. Secondly, community involvement is thought to be an effective way for promoting quick uptake and communal support for accountable, politically-viable, public health programmes (Bryan *et al.* 1994, Fillinger *et al.* 2008, Killeen *et al.* 2002b, Mukabana *et al.* 2006, Toledo *et al.* 2007, Townson *et al.* 2005, WHO 2004, Winch *et al.* 1992).

Of the numerous options for supplementing LLINs and IRS with complementary vector control measures (Ferguson *et al.* 2010), is the historically-established strategy of larval source management (Keiser *et al.* 2005, Killeen 2003, Killeen *et al.* 2002b, Kitron and Spielman 1989, Townson *et al.* 2005, WHO 2004). Larval source management embraces environmental management and the regular application of insecticides to aquatic habitats (Rozendaal 1997, Walker 2002, Walker and Lynch 2007) which have not or cannot be modified or eliminated because of their ownership or function (Mutuku *et al.* 2006). The efficacy and effectiveness of larviciding has recently been evaluated in a range of research and programmatic settings, on scales varying from small rural villages (Fillinger and Lindsay 2006, Fillinger *et al.* 2009, Shililu *et al.* 2003) all the way through to extensive tracts of a large city (Fillinger *et al.* 2008, Geissbuhler *et al.* 2009). The Urban Malaria Control Program (UMCP) in Dar es Salaam, Tanzania represents an example in which larviciding was implemented on large scales by local government actors through sustainable and affordable systems embedded in routine municipal services (Fillinger *et al.* 2008, Mukabana *et al.* 2006, Vanek *et al.* 2006). Specifically, the UMCP implemented three main routine tasks, (1) routine aquatic habitat surveillance, (2) regular application of microbial larvicides and (3) adult mosquito monitoring (Fillinger *et al.* 2008, Geissbuhler *et al.* 2009). All these activities are implemented by community owned resource persons (CORPs) assigned to well defined areas of responsibility that the CORP ideally lives in or close to (Chaki *et al.* 2011, Chaki *et al.* 2009, Fillinger *et al.* 2008, Vanek *et al.* 2006) and that are typically smaller than $1km^2$ (Dongus *et al.* 2011a, Dongus *et al.* 2007).

While this article focuses on the third activity, namely surveillance of adult mosquitoes, the spatial extensiveness and temporal intensiveness required of this monitoring platform are defined by the challenges of comprehensive larval surveillance and control (Killeen *et al.* 2006b). Specifically, habitats must be searched for and treated on a weekly bases because microbial larvicides have little residual effect (Majambere *et al.* 2007) and *An. gambiae* complex mosquitoes develop from egg to adult in less than seven days, in habitats that can be ephemeral and difficult to detect (Gillies and DeMeillon 1968, Mutuku *et al.* 2006, Mutuku *et al.* 2009, Sattler *et al.* 2005). It is therefore essential to independently monitor adult vector densities so that gaps in larval surveillance and control (Chaki *et al.* 2011, Chaki *et al.* 2009), as well as influx of dispersing vectors from neighbouring areas can be detected. While larval surveillance is clearly required to rapidly respond to such dynamic ecology, such surveys only report on known habitats and locally potential to generate adult mosquitoes. To enable evidence-based, responsive management of the large, decentralized community-based (CB) labour force, which executes larval control on a daily basis (Fillinger *et al.* 2009), an equally spatially- extensive (Figure 4.2.1) and temporally-intensive surveillance system is required (Dongus *et al.* 2011a, Dongus *et al.* 2007, Fillinger *et al.* 2008). To address this need, the UMCP conducted routine monitoring of adult mosquitoes densities as the primary, most direct indicator of program performance on a weekly basis (Fillinger *et al.* 2008, Geissbuhler *et al.* 2009).

The initial monitoring system utilised outdoor human landing catch (HLC) because it was the only method known to reliably catch *Anopheles* malaria vectors with satisfactory sensitivity in this setting (Fillinger *et al.* 2008). The previous system consisted of a team of 67 CORPs who conducted monthly surveys of 268 locations distributed across 55 km^2 of Dar es Salaam with a population of >600,000 people (Dongus *et al.* 2011a, Dongus *et al.* 2007, Fillinger *et al.* 2008, Geissbuhler *et al.* 2009, Geissbühler *et al.* 2007). Each CORP was assigned four sites in one particular neighbourhood (*mtaa*), one of which was surveyed each week by HLC for one night. Although this interim transmission monitoring system using HLC did produce useful surveillance data, the laborious nature of implementing this community-based scheme on the ground and the vertical management system required to maintain reliable performance were costly and difficult to sustain indefinitely as a routine activity (Sikulu *et al.* 2009). Moreover, the potential health risks associated with exposure to potentially infectious mosquito bites during human landing catches necessitated the development of a mosquito trapping method which is not only more scalable, affordable and practical (Govella *et al.* 2011, Govella *et al.* 2009, Sikulu *et al.* 2009) but also safe for the operator (Govella *et al.* 2010a).

The Ifakara Tent Trap (ITT) (Govella *et al.* 2010a, Govella *et al.* 2011, Govella *et al.* 2009, Sikulu *et al.* 2009) was developed to address these specific problems and operates passively all night long without skilled personnel using a single human volunteer who simply sleeps in the tent to act as bait. A number of efficacy studies with the B-model confirm that it is the only reasonably sensitive alternative to HLC (Govella *et al.* 2011, Govella *et al.* 2009) in urban Dar es Salaam and a small scale pilot study indicated that it is effective in the hands of CB staff with minimal supervision (Sikulu *et al.* 2009). Furthermore, the latest C-model has been shown to fully protect the user and may even be more sensitive (Govella *et al.* 2010a).

Here we report an evaluation of the effectiveness of a novel extensive and intensive decentralized system for routine entomological surveillance, in which the C design of the ITT was applied by community-based personnel. The effectiveness of this decentralised system was contrasted with an independent quality assured centralized system applying both ITT-C and HLC. The results of these alternative decentralized and centralized surveys were compared with cross-sectional household malaria infection surveys to assess their respective epidemiological relevance in the same set of sampled locations.

4.2 Methodology

4.2.1 Study Area

Dar es Salaam is a hot, humid coastal city and experiences two rainy seasons: the short rains from mid-October to early-December followed by the long, more intense rains from March to June. Dar es Salaam is Tanzania's biggest and most economically important city with an estimated population of 3.3 million in 2010, living within an administrative region of 1400 km^2 (Anonymous 2003b, UN 2010). The city is divided into three municipalities, namely Kinondoni, Temeke and Ilala, and these municipalities are further divided into a total of 72 wards. The study site encompasses 31 administrative wards at the heart of the city, comprised of one set of 15 wards previously described as the UMCP study area (Geissbuhler *et al.* 2009) and another 16 neighbouring wards, totalling approximately 2.65 million residents living in an area of 160 km^2 (Anonymous 2003b). Before the initiation of larviciding, the area experienced modest malaria transmission rate with an entomological inoculation rate (EIR) of approximately one infectious bite per person per year (Fillinger *et al.* 2008, Geissbuhler *et al.* 2009). The main malaria vectors are members of the *Anopheles gambiae* complex which prefer to feed outdoors and may therefore be only moderately vulnerable to control with indoor-targeted insecticidal means such as ITNs (Geissbühler *et al.* 2007, Govella *et al.* 2010b).

4.2.2 The Dar es Salaam UMCP

All UMCP activities are coordinated by the City Medical Office of Health, and fully integrated into the decentralized administrative system of Dar es Salaam (Fillinger *et al.* 2008, Mukabana *et al.* 2006). The UMCP operates on all six administrative levels of the city: the city council, the 3 municipal councils it oversees, the 15 wards chosen from those municipalities, containing 67 neighbourhoods referred to as *mitaa* in Kiswahili (singular *mtaa*, meaning literally street), and more than 3000 housing clusters known as ten-cell-units (TCUs), each of which is subdivided into a set of plots corresponding largely to housing compounds (Dongus *et al.* 2011a, Fillinger *et al.* 2008, Geissbuhler *et al.* 2009). The main tasks of the 3 upper levels within UMCP are programme management and supervision, whereas actual mosquito larval surveillance and control is organized at ward level and implemented at the level of TCUs and their constituent plots. In principle, a TCU is a cluster of ten houses with an elected representative known as an *mjumbe*, but typically comprises between 20-100 houses in practice (Dongus *et al.* 2007). As a prerequisite for effective management of a larviciding program, the UMCP implemented routine larval habitat surveillance between 2004 and 2008 (Chaki *et al.* 2011, Chaki *et al.* 2009, Fillinger *et al.* 2008). From March 2006 to date, the UMCP implemented regular larviciding of all mosquito breeding habitats as a means to kill aquatic mosquito stages, prevent adult emergence and reduce malaria incidence and prevalence through a community-based but vertically managed delivery system (Chaki *et al.* 2011, Chaki *et al.* 2009, Fillinger *et al.* 2008, Mukabana *et al.* 2006, Vanek *et al.* 2006). UMCP began systematic larviciding in 3 wards (one from each municipality) in April 2006 (Chaki *et al.* 2011, Chaki *et al.* 2009, Geissbuhler *et al.* 2009, Vanek *et al.* 2006), following complete participatory mapping of the area (Dongus *et al.* 2011a, Dongus *et al.* 2007) and CB baseline surveys of the breeding habitats. The program subsequently scaled-up larvicide application to 9 wards in May 2007. In March 2008 the programme was extended to all the 15 wards of the original study area. In this particular study, community-based adult mosquito surveys were set up across the original 15 UMCP wards plus an additional 16 adjacent wards from outside the study area to include non-UMCP wards chosen from the same three municipalities where there was no larviciding taking place. Overall, this 160km^2 area contained 31 wards, 85 *mitaa*, approximately 8,000 TCUs and approximately 2.65 million residents (Figure 4.2.1).

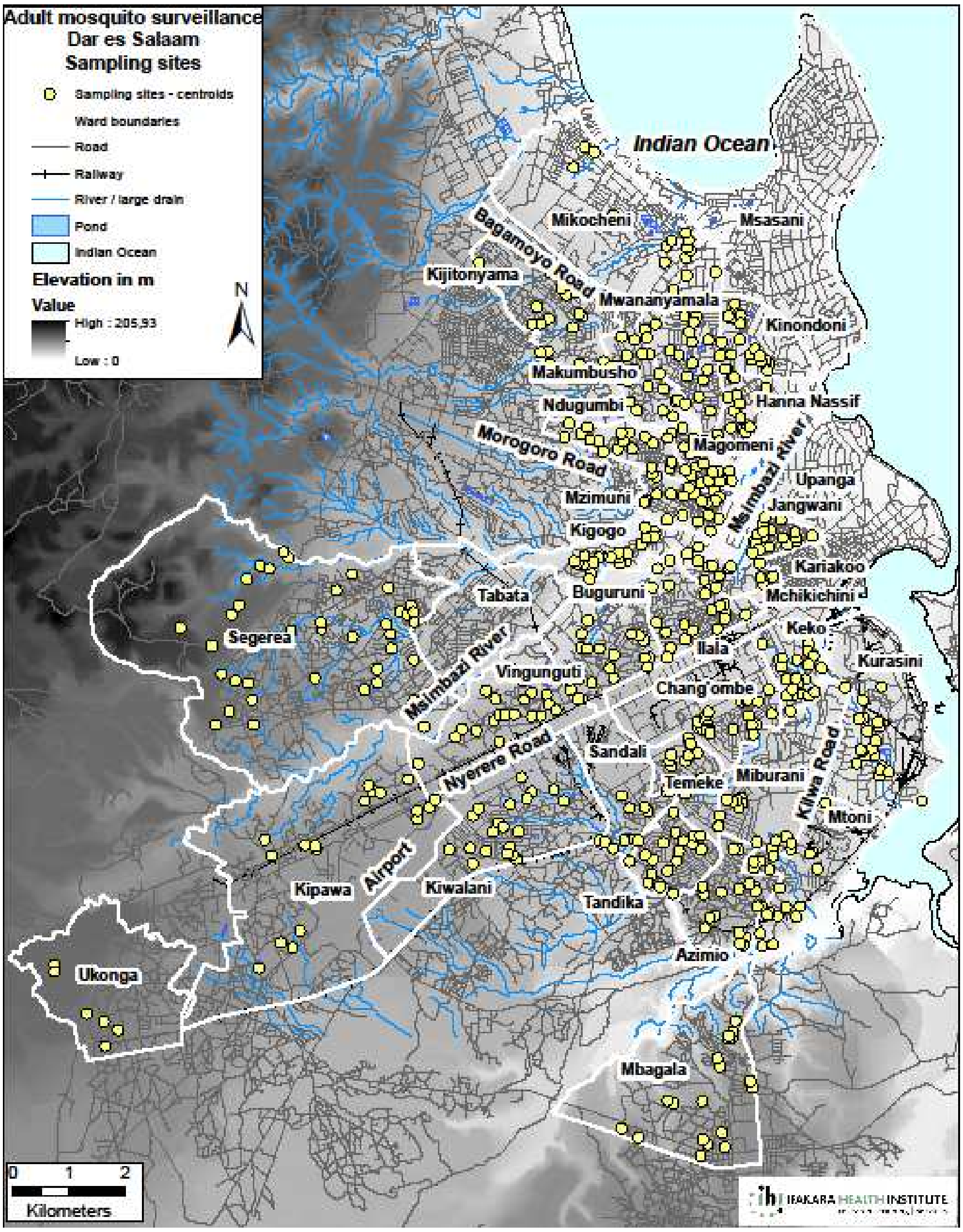

Figure 4.2.1: Map of Dar es Salaam showing the wards and respective locations where community-based adult mosquito surveillance was conducted.

4.2.3 Routine programmatic adult mosquito surveillance by community-based personnel

Based on a pilot-scale evaluation in 12 wards (Sikulu *et al.* 2009), a CB scheme for trapping adult mosquitoes using the C-design ITT (Govella *et al.* 2010a) was developed and implemented as a replacement for the previous system that relied on HLC (Geissbuhler *et al.* 2009). The entomological survey was initially set up across the previous 15 UMCP intervention wards, each of which comprised of a cluster of 20 sampling sites, making a total of 300 sentinel sites distributed across the UMCP study area that were routinely surveyed on monthly basis. This was primarily meant to serve as a tool for routine monitoring of progress of the larviciding program activities by identifying areas with residual vector populations and, presumably, malaria transmission. Adult mosquito surveillance was therefore decentralized to ward level to coincide with management practice for concurrent community-based larval surveillance and larvicide application. The system adopted a decentralized sampling protocol (Sikulu *et al.* 2009), that enabled unskilled community members, rather than trained entomologists sent from a centralized team, to capture, record and submit mosquito samples, without any night time supervision by the research team, and with only occasional contact with program staff. This system was modified from that of the original pilot (Sikulu *et al.* 2009) so that only one volunteer per ward was recruited, compared to one per neighbourhood or *mtaa* (3-7 per ward) in the pilot system, to conduct monthly surveys of 20 locations per ward rather than weekly surveys of 4 locations per neighbourhood (12-28 per ward).

Overall thirty one, 15 volunteers from the 15 original UMCP wards were recruited and remunerated at a rate of 3500 Tanzanian shillings (2010 US$ 2.70) per night of trapping. Each volunteer took responsibility for trapping mosquitoes for one night per month at each of the 20 locations within his or her assigned ward. They were allowed to choose, at their own discretion, which nights of the week (Monday to Friday) they would sleep in the traps, the sequence they would visit each of their 20 assigned locations, and what time they entered and left the traps, under the condition that they recorded these dates and times in standardized forms. This was considered necessary for promoting a sense of ownership and responsibility for the project, and making working conditions relaxed, conducive and flexible so that the modest remuneration remained sufficiently attractive to retain CORPs and minimize any incentive to fabricate data. Furthermore, there were no consequences to the CORPs for not trapping on a particular night so long as all the 20 sites were sampled at any week day of that particular month. The 20 sampling sites in each ward were deliberately chosen by the local leaders and the CORP, with the intention that they were well-distributed across the ward, close to obvious *Anopheles* larval habitats, and preferably within walled compounds so that safety of the sleeping volunteer was assured.

The volunteers were supplied with all the necessary materials including paper cups, air-tight containers, aspirators, petroleum ether and bicycles for transport. This allowed them to continuously trap, collect and store mosqutoes for a period of one week, recording their observations and trapping sequence daily on a form they were provided with. Samples were submitted each week to the central laboratory for further processing using the bicycles that each CORP was provided with to assist them in moving the trap between the sites within the ward. Each night the trap was erected outside of the designated house and the volunteer slept in it over night to act as a bait to attract human-feeding mosquitoes. Note that the user is completely protected by the fine netting trap chambers where the mosquitoes are trapped (Govella *et al.* 2010a). Mosquitoes were removed from the trap chambers using aspirators, transferred into paper cups, and then anesthetized with a small ball of cotton wool soaked in petroleum ether. Dead mosquitoes were then transferred into an air-tight (1.5ml Eppendhorf tubes, Nantong Shenhua Laboratory Apparatus Co., Ltd) container half-filled with silicagel for storage and preservation before submission to the central mosquito laboratory each week. To control for and minimize data fabrication by CORPs, standardized forms were supplied (Appendix 3) and they were obliged to record the approximate number of each relevant mosquito taxon caught, early each morning immediately after they finished collecting, and to document confirmation of his visit with the signature of the house owner where the trapping took place that particular night. At the laboratory, the samples were received by a technician who verified their content before formally recording their acceptance in good condition in a registry book.

This protocol for routine CB sampling with ITT-C across the original 15 UMCP wards, where larviciding had already been established as a routine activity, began in February 2009 whereas the 16 non-intervention wards outside this area started in October 2009. These additional wards were included as a preparatory step for scaling up city-wide vector surveillance and larviciding, as well as to enable subsequent evaluation of the protocol as applied at large scale across the full range of vector densities found in the city. Overall, this CB system for routine surveillance of mosquito biting intensities spanned over 620 designated sentinel sites (clusters of twenty in each of the 31 wards) of which 615 were actually sampled on a monthly basis in practice (Figure 4.2.1).

4.2.4 Randomized quality assurance entomological surveys

To assess the quality of data collected by the decentralized, routine adult mosquito surveys described above, two quality assurance (QA) adult mosquito surveillance teams were recruited, each comprising five catchers earning slightly more than their counterparts in the routine CB system. The first team, earning 4000 TShs (2010: US$ 3.50 per person per night) was responsible for repeating adult mosquito collection using ITT at five locations scheduled one day after the routine CB mosquito surveillance team had applied the same trapping method in these same locations. The sampling framework for the sites involved randomly selecting five sites from the list of locations where the CB collectors had set their traps the previous night. Therefore, this team was responsible for repeating adult mosquito sampling at randomly chosen locations, over four days of the week (Tuesday to Friday), totalling 20 locations sampled for resurvey by the QA team each week. The second team, earning 8000 Tanzanian Shillings (2010: US$6.15) per day, was responsible for repeating adult mosquito collections using HLC at the same randomly-selected locations used the previous nights for QA-ITT and the night before that for routine CB collections with ITT. This second team worked three days per week (Wednesday to Friday) at the same five randomly chosen locations as the first QA team, totalling 15 locations sampled per week. Outdoor HLC was conducted at each of these houses from 6 pm to 7 am for a period of 45 minutes every hour, allowing for 15 minutes break each hour, as previously described (Geissbuhler *et al.* 2009, Geissbühler *et al.* 2007). These two QA teams were vertically and regularly supervised, including random night time spot checks by the research team for quality control. The locations selected for QA follow up was not disclosed to either the QA teams nor to the supervising research staff until the day after the routine survey was set up, in the late evening of the day for the first QA surveys using ITT. This was necessary to avoid any possibility of collusion between CORPs in the routine and QA teams and thereby minimize risk of data fabrication. CORPs from the two QA teams were dropped by vehicle at their scheduled stations, accompanied by the field supervisor. The mosquitoes collected by the ITT-C and HLC QA teams were collected by vehicle and taken to the central laboratory the following morning when the catchers had finished their collections.

Laboratory Processing and Data Reporting

In the laboratory, all mosquitoes were identified morphologically using taxonomic keys (Gillies and Coetzee 1987) as males or females, and as *An. gambiae s.l.*, *Anopheles funestus*, *Anopheles ziemanni*, *Culex* species, or *Aedes* species. Abdominal status was scored as gravid/semi-gravid, fed or unfed for all the *Anopheles* and for Culicines. All *Anopheles* caught were subsequently desiccated over silica gel and kept at room temperature until they were further processed. These classification and count data were first recorded on standardized paper forms (Supplementary online material) and then reported using mobile phones with specifically designed menus and made available to stakeholders and project staff at the following link http://e-surveillance.ihi.or.tz/ (pass code made available upon request). This web site was also loaded with automatically generated (pre-coded *R* script) weekly synthesis report for the UMCP management staff and other stakeholders to review at will. A wing or a leg of every *An. gambiae s.l.* mosquito caught was analyzed by PCR to identify its exact species within the *An. gambiae* complex (Scott *et al.* 1993). An enzyme-linked immunosorbent assay (ELISA) using a monoclonal antibody that recognizes a repetitive epitope on the circumsporozoite-protein of *Plasmodium falciparum* was used to establish malaria sporozoite infection status in each individual *An. gambiae s.l.* specimen (Burkot *et al.* 1984).

4.2.5 Cross sectional epidemiological survey

All the 620 sites used for the routine entomological surveillance were mapped to the TCU level (Dongus *et al.* 2011a, Dongus *et al.* 2007) and the households within each were carefully listed. Three teams of four people, comprised of a supervisor, community-based health nurse and two interviewers conducted the cross-sectional household surveys (March to August 2010) in all households of the house or housing compound (median= 4 households) which routine CB mosquito surveillance was conducted. All people occupying the household were included in the survey, excluding children who were three months old or less. Systematic screening of all the inhabitants of each selected household who were present at the time of the survey, and consented to participate, was carried out to determine their malaria infection status. Parasitological examination was carried out by the community-based health nurses by finger prick with a sterile lancet. A small amount (5µl) of blood was drawn from consenting residents using micro pipettes and placed on MAL-Pf® (ICT Diagnostics, Cape Town, Southa Africa) malaria rapid diagnostic test kits (RDTs) using histide rich protein-2 as the test antigen (HRP-2). Such HRP-2 RDTs, including this specific kit, have increasingly been proven sensitive, reliable and accurate for routine malaria diagnosis in the field (Clinton 2009, Moody 2002, Murray and Bennett 2009, Tanowitz *et al.* 1999). While this specific test kit is prone to a phenomenon called prozone that results in weak responses to very high density parasitemias, no false negatives were documented in a recent evaluation of this and other comparable HRP-2 based products (Gillet *et al.* 2011). Questionnaire responses and RDT results were recorded electronically in the field using Socket SoMo 650 Series (Socket Mobile, Inc) portable digital assistants programmed in Visual CE.

4.2.6 Data Analysis

All the data were entered in coded numeric form, cleaned, restructured and analyzed using SPSS® 18.0 except where described otherwise.

The mean relative sensitivity of the three surveillance methods was estimated by fitting a generalized linear model (GLM) with a negative binomial distribution to the mosquito catch for each recorded trap night, treating surveillance method as a categorical independent variable with location as the subject and date as a within-subject source of variation with first order autocorrelation. Correlation between the mean catch (transformed as logarithm (y+1)) at each location obtained with the three alternative vector surveillance methods were tested pair-wise using Pearson's linear correlation test. Associations between the relative sensitivities of CB trapping with ITT and mosquito densities measured by the two QA survey methods were tested for using binary logistic regression (Collett 2003). Specifically, GLMs were fitted to the proportion of all mosquitoes caught by the CB-ITT in a given location and week where all methods were applied.

We aggregated the catches of female *An.gambiae* or *An.funestus* and Culex spp. by survey method, yielding mean catches for each method per trap night per location. On several occasions, all the three survey methods recoded zero values even after aggregation so an artificial incremental scatter was added to generate the none-zeros and allow separation and visualization of otherwise identical data points. Since divisions by zero gives infinite values, data for each location thus included the sum of several observations of the catches for the specific survey method. In order to establish the density dependence of sampling sensitivity of ITT through either CB or QA methods, the mean catches of the collections by alternative survey methods (CB-ITT and QA-ITT) was divided by the sum of the QA (QA-ITT +QA-HLC) collections, and this denominator was treated as the continuous independent variable in a generalized linear model.

To allow direct comparison of the three surveys in terms of cost-effectiveness only the direct and non-direct expenditures incurred by each system, during the period when all three systems were operating in parallel are considered. These included monthly personnel costs (salaries and volunteer allowances) for each team, supplies and transport costs. Transport costs comprised of the upfront costs for buying a bicycle or a vehicle (for both the CB and QA-surveys, respectively) plus the three years or ten years-depreciated costs (for the bicycles and vehicle, respectively) and their respective monthly-recurrent (service and maintenance) costs. All cost estimates are presented in Tanzanian shillings as recorded at the time they were incurred and then converted into 2010 US$ at a rate of 1408.02 shillings per dollar.

To qualitatively examine differences in age-prevalence profiles associated with malaria transmission hot spots, infection prevalence data from household surveys were initially stratified based on either the presence or absence of any detectable primary vectors (any *An. gambiae s.l.* or *An. funestus* caught) by a given survey method. Subsequently, this approach was refined to stratify on the basis of being amongst the 5% highest mean catches of primary vectors. In all cases, differences between the two strata for each vector surveillance method, in terms of the distribution of infection probability among the following age classes, was tested by χ^2 analysis using Microsoft Excel®: less than 5 years, 5 to 19 years and 20 years or more.

Explanatory logistic regression models (GLMM) of malaria infection prevalence were fitted and selected in a forward stepwise manner using *R* version 2.12.2. The association of malaria prevalence with the following independent variables was assessed: mean catch at a given location with each individual entomological survey type, LLIN use, presence of eaves, presence of ceiling, presence of window screening (good indicators of socioeconomic status), larviciding activity, use of insecticide consumer products, travel in the previous month or residence elsewhere, sex and living with both parents. To adjust for spatial and temporal heterogeneities TCU location identity and date were incorporated into all models as random effects. Only variables exhibiting evidence of association with malaria infection risk ($P \leq 0.05$) when tested as a single categorical independent variable were retained in the model (Bolker *et al.* 2009, Mundry and Nunn 2009). The variables with the lowest P-value obtained in the exploratory analysis were included first. Based on qualitative examination of age-prevalence relationships in this dataset (see results), this logistic regression analysis was applied only to children and teenagers (<19 years) because the relationship between their exposure and infection prevalence appeared to be higher and to increase with age in areas with higher vector density.

4.2.7 Ethical consideration and informed consent

The study received ethical clearance from the Medical Research Coordination Committee of the Tanzanian National Institute of Medical Research (Reference numbers NIMR/HQ/R.8a/Vol.IX/279 and 324). Informed consent was obtained from all the participants, including the mosquito catchers and the house owners where the sampling took place, as well as the participants in the household surveys. All the volunteers recruited for conducting HLC were provided with prophylactic treatment with Atovaquone-Proguanil Hydrochloride (Malarone®) free of charge which they were obliged to take once a day to prevent malaria infection. In order to deal with the possibility of poor compliance or drug failure, participants in mosquitoes-trapping surveys who developed any symptoms such as fever, chills, headache or nausea, were tested for malaria parasites and would have been offered free treatment if found to be infected but this eventuality never occurred during the study. All participants in either the household surveys found to be infected with malaria were offered supervised treatment with Artemether-Lumefatrine (Coartem®; Novartis Pharma AG, Basel, Switzerland) prescribed by a clinical officer and provided by the community health nurse, following national treatment policies and guidelines, as soon as the RDT test was complete. However, if the participant refused this offer of treatment, they were referred to a nearby health facility and given all required transport and other logistical assistance to attend. Women of child-bearing age found to be infected with malaria were offered treatment with Artemether-Lumefatrine unless they were known or suspected to be pregnant and in their first trimester, in which case were instead treated with oral quinine as per national guidelines.

4.3 Results

Mean mosquitoes catches by each surveillance system over the course of the study are presented in Figure 4.3.2. Of the 372,655 mosquitoes caught by both CB and QA entomological surveillance systems the vast majority (99%) were assorted Culicine taxa: *Culex* spp. (372,161) and *Mansonia* spp. (7). Of the small minority of mosquitoes caught which were *Anopheles* (0.13%; 487), most were *An gambiae* sl (92.0%; 448) with the remainder comprising *An.funestus*

(0.61%; 3) and *An.ziemanni* (7.39%; 36). Consistent with previous reports from this setting (Geissbuhler *et al.* 2009, Sikulu *et al.* 2009), the majority of *An. gambiae* sl specimens successfully amplified by PCR were *An. gambiae* ss (77.5%; 178) with the remainder being *An. arabiensis* (21.91%; 39). The trapping system had no influence upon sibling species composition (χ^2=0.157, d.f. =2, P=0.924). Both successfully amplified specimens from the *An. funestus* group were *An. funestus* ss. Only one (0.56%) of the *Anopheles gambiae* ss caught was infected with *P. falciparum* sporozoites.

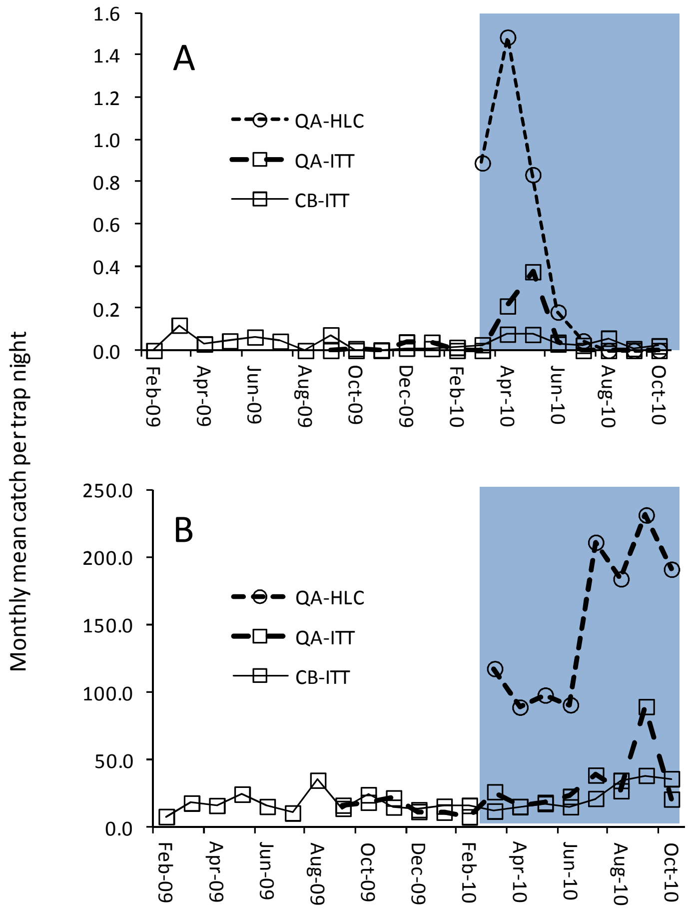

Figure 4.3.2: The monthly mean *Anopheles gambiae* (**A**) and Culicine (**B**) densities from the three independent alternative surveys routine Community-based surveys using Ifakara Tent Trap (CB-ITT), Quality assurance surveys based on both human landing catch (QA-HLC) and tent trap (QA-ITT).

4.3.1 Relative sensitivity of alternative survey systems using tent traps

Overall, the sensitivity of ITT-C (Govella *et al.* 2010a) for trapping both *Anopheles* and Culicines (Table 4.3.1) was far lower than HLC when applied by either CB or QA surveys. These relative sensitivity estimates for the C design of the ITT were approximately half of those previously reported for its predecessor, the B design (Govella *et al.* 2011, Govella *et al.* 2009, Sikulu *et al.* 2009), for both mosquito taxa. The ITT was less sensitive for both mosquito taxa when applied through the CB surveys than the QA surveys (Table 4.3.1) but not dramatically so (Relative rate [95% confidence interval] = 0.536 [0.406,0.617], P=0.001 for *An.gambiae s.l.* and 0.747 [0.677,0.824], P<0.001 for *Culex* spp.). However, the mean mosquito catches from the CB-ITT surveys, but not those from the QA-ITT surveys, positively correlated with those from the QA surveys using the gold standard HLC method (Figure 4.3.3).

Both the CB and QA surveys with ITT exhibited high density-dependent sensitivity when compared to the gold standard QA surveys with HLC (Figure 4.3.4), which is consistent with previous observations (Govella *et al.* 2009). All ITT surveys were clearly less sensitive at high mosquito densities compared to the reference QA surveys with HLC but at very low densities the ITT is at least as sensitive as the gold standard HLC. It is notable that not only is the intercept of the plot for the CB-ITT surveys lower than for QA-ITT surveys, the downward slope as mosquito density increases is much steeper (Figure 4.3.4). This suggests that high mosquito densities reduce the sensitivity of the ITT and that standards of practice for its use by CB staff are also adversely affected by high mosquito densities or associated environmental variables, the most obvious of which is rainfall.

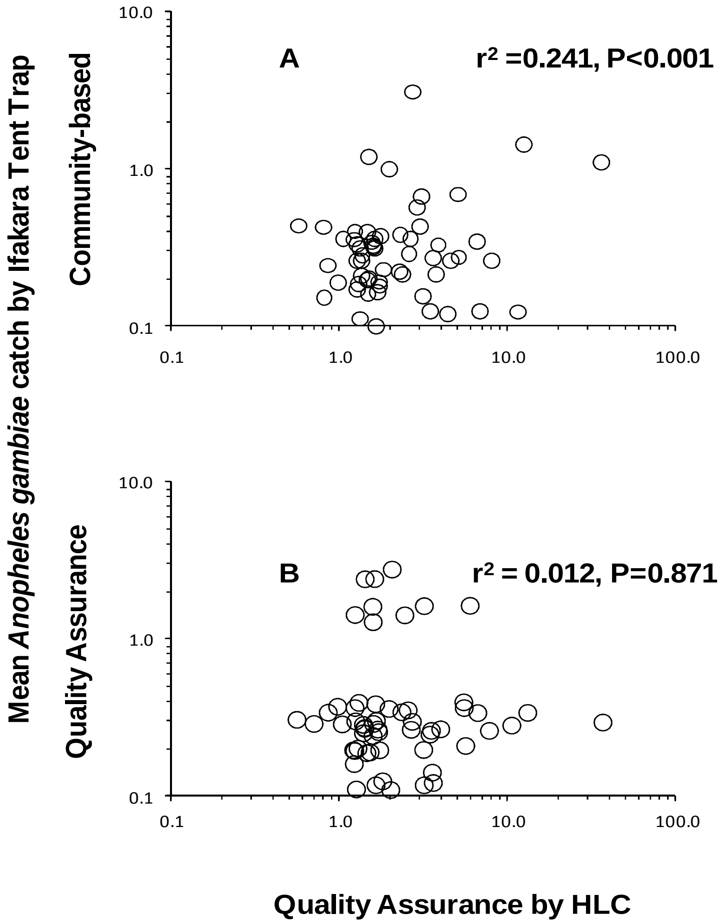

Figure 4.3.3: Correlation of the alternative ITT-C based surveys efficiency, relative to quality assurance surveys based on human landing catch (HLC) gold standard reference method for sampling *An. gambiae s.l.* plotted against CB-ITT (**A**) and QA-ITT (**B**) with scatter (*X* or *Y*) presented as *X* + (S *(1+ *X)* or *Y* + (S *(1+ *Y)* where S is a random number between 0.1 and 0.4 added to improve visualization.

Table 4.3.1: Relative sampling sensitivity of community based (CB) and quality assurance (QA) surveys of mosquitoes with ITT, compared with QA surveys by human landing catch (HLC), as estimated by generalized linear models (GLM).

Method	Number caught	Trap nights	Locations surveyed	Mean trap nights per location	Mean Catch[95%CI]	Relative Rate [95%CI]	P
Anopeheles gambiae s.l.							
CB-ITT	208	8171	615	13.29	0.026 [0.021,0.033]	0.079 [0.051,0.121]	<0.001
QA-ITT	53	931	293	3.18	0.057 [0.039,0.085]	0.182 [0.101,0.328]	<0.001
QA-HLC	187	335	240	1.39	0.560 [0.385, 0.815]	1.00*	NA
Culex spp							
CB-ITT	287,398	8171	615	13.29	20.7 [19.3, 22.0]	0.153 [0.137, 0. 171]	<0.001
QA-ITT	35,642	931	293	3.18	27.1 [23.9, 30.8]	0.215 [0.190, 0. 243]	<0.001
QA-HLC	49,121	335	240	1.39	147.7 [133. 8,163.0]	1.00*	NA

NA: not applicable
CI: confidence interval
* Reference category

Despite the much lower average sensitivity of CB surveys with ITT per person night of sampling (Table 4.3.1), and declining sensitivity observed as mosquito densities increase (Figure 4.3.4), overall CB surveys had slightly greater absolute sensitivity in terms of the total number of mosquitoes caught (Table 4.3.2). This occurs because it was possible to maintain these CB surveys in a slightly larger number of locations but, more importantly, because they enabled consistent longitudinal monthly monitoring of mosquito density, resulting in a far greater number of samples per survey location (Figure 4.3.5, Table 4.3.2). By comparison, the well-controlled QA surveys were clearly more sensitive per person-night of trapping (Table 4.3.1) but could only visit any given sites within this large, widely distributed set of locations (Figure 4.2.1) on one or two occasions per year (Figure 4.3.5).

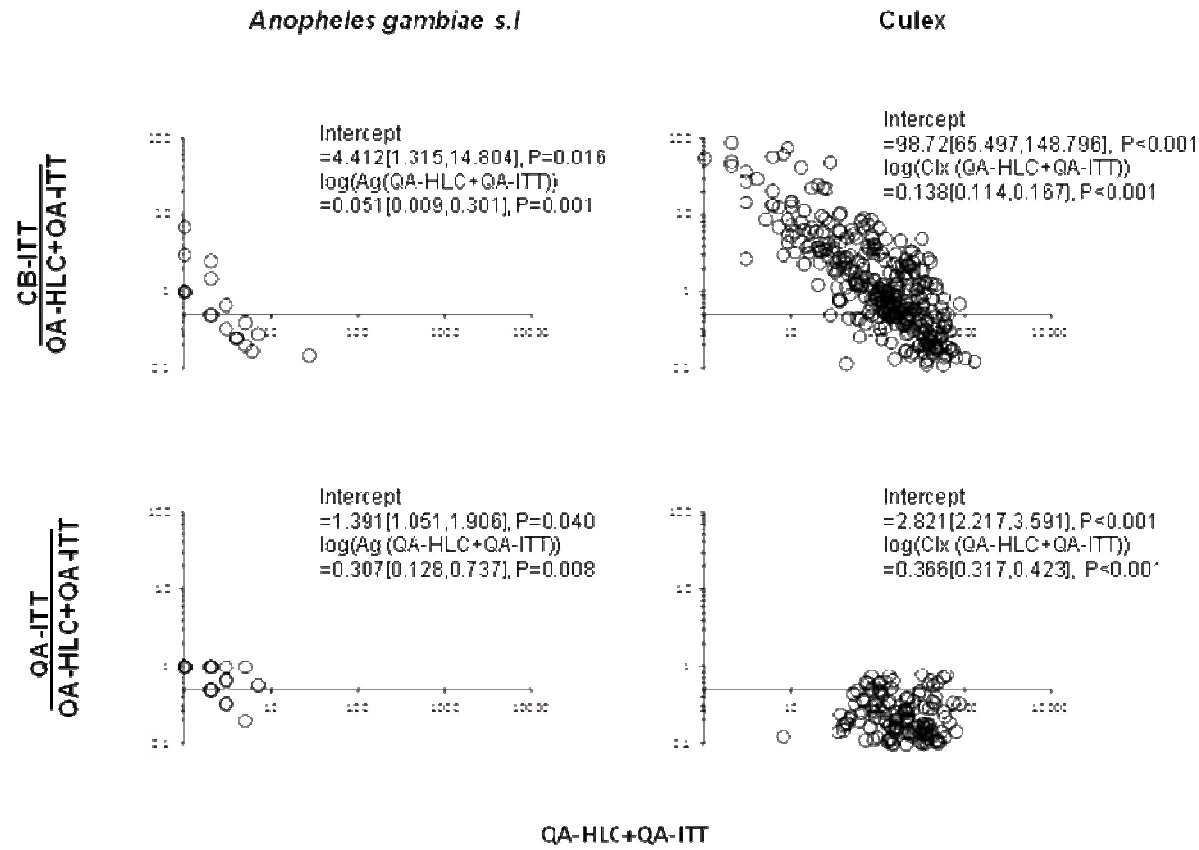

Figure 4.3.4: Density-dependence of alternative ITT-based survey methods relative to the HLC-based QA surveys for sampling *Anopheles gambiae s.l.* (A and C) and *Culex* spp. (B and D). The density-dependence is illustrated by plotting the alternative survey method catches divided by corresponding sum of catches from QA-ITT and QA-HLC or both against the absolute CB_ITT catches.

Table 4.3.2: Crude estimates of the costs for each surveillance method per night of trapping and per *Anopheles gambiae s.l.* caught over the selected period outlined in figure 2 when all three surveillance systems were simultaneous in operation. All costs are presented in Tanzanian Shillings (Tsh) at a mean 2010 exchange rate of 1408.02 per US$.

Estimated Parameter	Community based	Quality assured	
	CB-ITT	QA-ITT	QA-HLC
Number of samples (person-nights)	4284	457	335
Number caught (mosquitoes)	171	42	169
Mean catch (mosquitoes per person-night)	0.04	0.09	0.50
Volunteer costs (Tsh)	14,994,000	1,828,000	2,680,000
Salary costs (Tsh)	21,209,820	24,413,820	24,413,820
Transport costs (Tsh)	3,100,000	20,340,000	20,340,000
Total Expenditure (Tsh)	39,303,820	46,581,820	47,433,820
Cost per sample (Tsh)	9,174.56	101,929.58	141,593.49
Costs per specimen of *An. gambiae s.l.* (Tsh per mosquito)	229,846.90	1,109,090.95	280,673.49

The intensive and extensive sampling frame of the CB surveys was possible because it was the cheapest of the three surveillance systems, costing approximately US$6 per night of sampling, compared to US$72 for running the QA-ITT-C and US$100 for the QA-HLC. In this low transmission setting with very sparse vector populations, entomological transmission surveillance proved an expensive undertaking but CB surveys proved the most affordable approach overall, despite their low sensitivity per person-night of sampling (Table 4.3.1). An average of US$163 was spent per specimen of *An gambiae s.l.* caught by the CB surveys, as compared to approximately US$787 and US$199 for QA surveys using ITT and HLC, respectively (Table 4.3.2).

4.3.2 Relationship between mean mosquito densities and malaria infection prevalence

Consistent with the range of vector densities observed in this urban setting (Figure 4.3.5), parasite prevalence data from the cross-sectional survey conducted at 357 of the locations confirmed that there was generally moderate transmission across the study area (Figure 4.3.6) with an overall prevalence of 13.3% (421/3173). Malaria infection prevalence consistently increased with age (OR [95%CI]= 1.23[1.059,1.392], P=0.0166), rather than peaking among young children as was observed previously in 2004-06 (Geissbuehler 2009, Supporting information box S1) indicating a loss of age- and exposure-associated immunity, presumably as a result of lowered mean transmission intensity across the area since that time or a reflection of asymptomatic adult infections that usually go unreported but were seen in this survey (Dongus *et al.* 2011b).

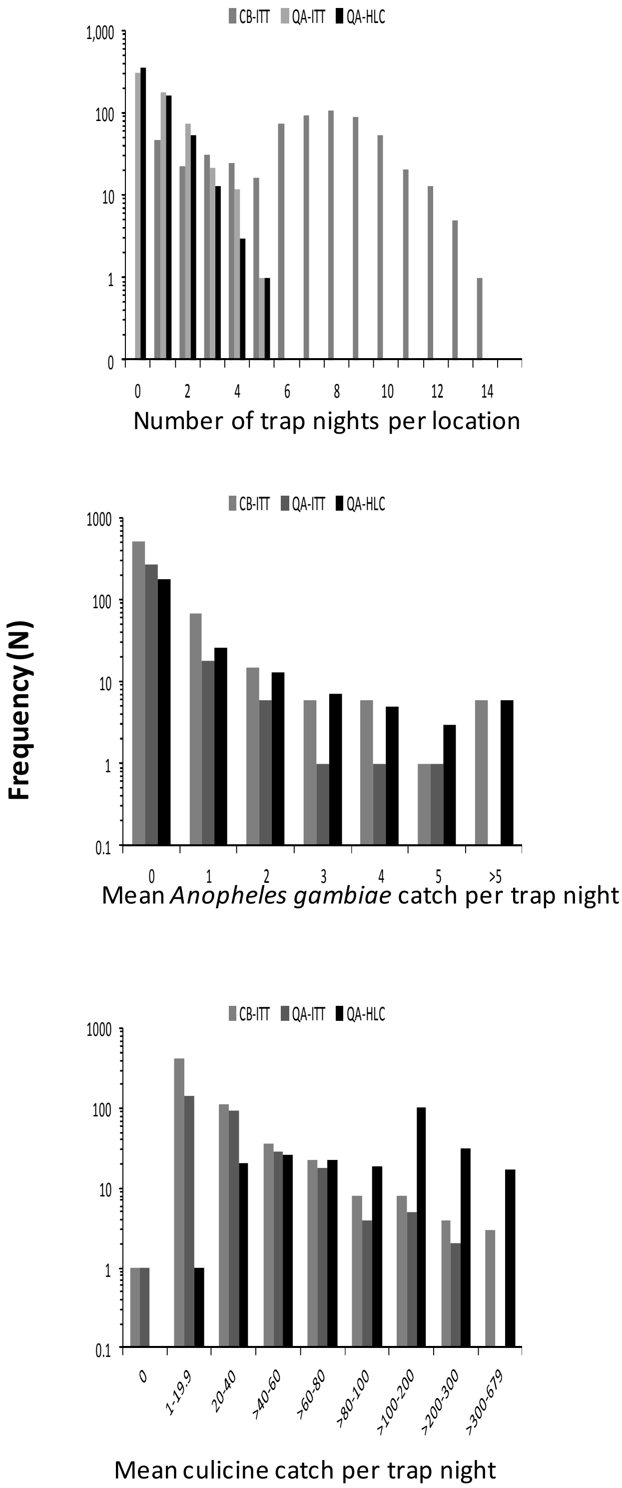

Figure 4.3.5: The frequency distributions of the person trap nights and mosquito densities across a range of survey locations by the three surveillance systems.

When the surveyed locations were stratified by vector density, using the three different survey systems and two alternative stratification criteria, prevalence peaked amongst older children and teenagers in the upper stratum for 5 out of 6 of the stratification criteria, and in one case the age-prevalence profile differed significantly between the strata (Figure 4.3.6). Further analysis with logistic regression, which allowed us to control for cluster effects associated with the sampled household clusters and the times they were surveyed, was therefore restricted to data from children and teenagers, amongst whom prevalence appears to be consistently positively related to both age and exposure to transmission.

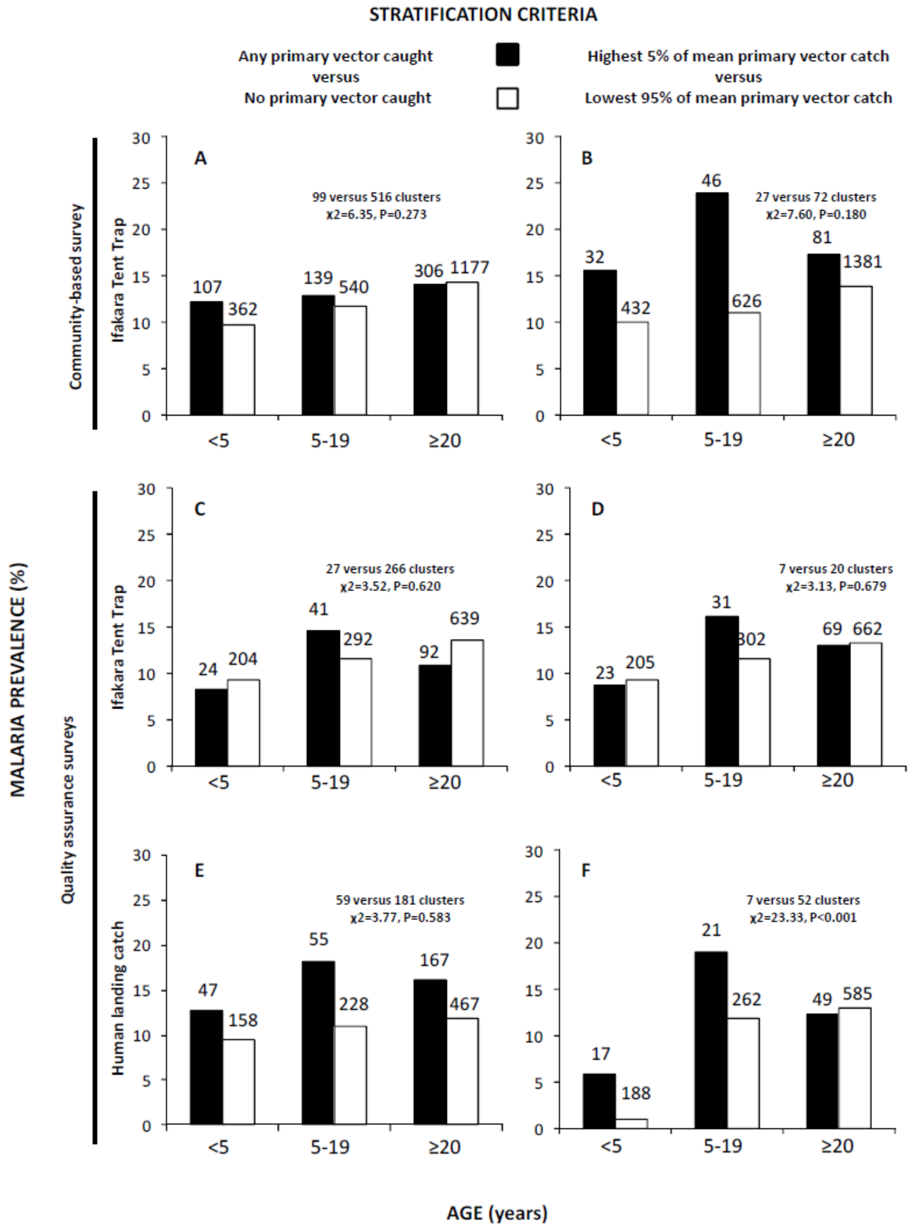

Figure 4.3.6: The relationship between age-specific malaria parasite prevalence distribution and mean vector density (*An.gambiae* and *An.funestus* combined) with different vector density intensity strata as determined by the three mosquito surveillance systems. *An gambiae*-mean catch=0, >0, (A, C and E) and (B) *An gambiae*-mean catch ≥ 0.25 (upper stratum-black bars) , versus ≤ 0.22 (lower stratum-white bars), and (D) *An gambiae*-mean catch≥4.00 (upper stratum-black bars) , versus ≤ 3.00 (lower stratum-white bars), and (F) *An gambiae*-mean catch≥1.00 (upper stratum-black bars) , versus ≤0.50 (lower stratum-white bars). The number at the top of each bar represents the total number individuals within particular age group from a set stratified surveyed clusters tested for malaria with mRDT.

Logistic regression analysis of infection status among residents under twenty years of age revealed that, other than location ($P \leq 0.001$) and the time of the survey ($P<0.001$), only the mean *An. gambiae* catch obtained from the CB surveys closely approached significance as a predictor of malaria risk (Table 4.3.3). The fitted model includes a significant positive intercept for the dependent variable (Table 4.3.3). Malaria infection risk was significant even where no primary vectors could be detected (Table 4.3.3, Figure 4.3.7), suggesting that appreciable malaria transmission amongst residents of Dar es Salaam occurs away from their homes. Baseline infection risk increases with *An. gambiae s.l.* density (Figure 4.3.7) and a four-fold increase in risk is estimated for individuals living in areas where an average of one *An. gambiae* is caught per person-night of CB surveillance with ITT (Table 4.3.3). Neither of the QA surveys of vector density using either ITT or HLC surveys had any appreciable predictive value of malaria prevalence (Table 4.3.3). Possible confounders that were tested and then excluded from all the final model included the type of floor, walls and roof (good indicators of socioeconomic status), use of insecticide consumer products, travel in the previous month or residence elsewhere, sex and living with both parents. Interestingly, having both closed eaves and a ceiling (P=0.532), or having one of them (P=0.804), or having one of these plus screened windows (P=0.850) or house owners' education (P=0.725) had no apparent impact on malaria risk despite their high levels of uptake arising from the perception that they protect against mosquito bites (Geissbuhler *et al.* 2009, Ogoma *et al.* 2009). Using an untreated net (P=0.607) also had no impact and it is also notable that neither of the interventions previously shown to confer protection (Geissbuhler *et al.* 2009), namely use of an LLIN (P=0.094) or living in an area covered with larviciding (P=0.428) had any significant protective effect or improved the model fit. Similarly, none of the three observed house characteristics namely type of floor (P=0.5432), wall (P=0.7602) and roof

(P=0.3694), as well as the use of personal protection measures such as insecticide consumer products including mosquito coils (P=0.3839), topical repellents (P=0.2566), or insecticide sprays (P=0.2799) had significant effect nor impact on the goodness of fit of model.

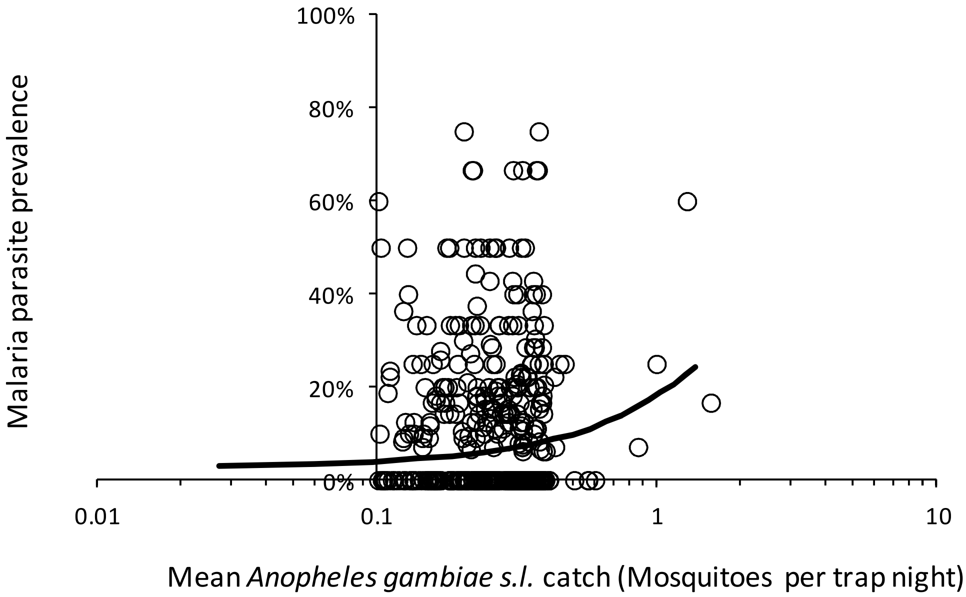

Figure 4.3.7: Correlation between mean catches of *Anopheles gambiae s.l.* per location and proportion of malaria infection prevalence per cluster. All crude absolute values (*X* or *Y*) are presented as *X* + (S *(1+ *X)* or *Y* + (S *(1+ *Y)* where S is a random number between 0.1 and 0.4 added to allow separation and visualization of otherwise identical data points. Solid curved-line depicts the mosquito density-malaria infection model with values represented as *X* + (0.25 *(1+ *X)* or *Y* + (0.25 *(1+ *Y)*.

Table 4.3.3: *Anopheles gambiae* mean catch per night as risk indicator for malaria parasite prevalence among children and teenagers (<20 years of age) as determined by fitting separate logistic regression models to data from each of the three survey methods. See table 2 for details of sample sizes for each entomological survey data set. Note that for all three models location ($P \leq 0.001$) and date ($P \leq 0.001$) included in the models were also highly significant random effects.

Survey type	OR[95%CI]	P
Community-based with ITT mean *Anopheles gambiae s.l.* catch	4.43 [1.091,17.956]	0.0373
Intercept	0.096[0.075,0.123]	<0.0001
Quality assurance with ITT mean *Anopheles gambiae s.l.* catch	1.01[0.465, 2.178]	0.989
Intercept	0.102[0.076,0.136]	<0.0001
Quality assurance with *HLC* mean *Anopheles gambiae s.l.* catch	0.94[0.823, 1.081]	0.448
Intercept	0.111[0.080,0.151]	<0.0001

Table 4.3.4: Comparison of the surveillance system described in this paper with some published large scale and longitudinal entomological surveys for monitoring interventions against malaria vectors.

Year (Duration of the surveys)	Study and location	Surveillance tool	Implementation platforms	Spatial scale	Temporal scale (trap nights)
2006-2007 and 2009-2010	**Abilio et al 2010** Zambezia province, central northern Mozambique	Window Exit Trap (WET)	Community-based (home owner) as stand alone	19 sentinel sites 6 households from each (114 houses sampled monthly)	788 trap nights
Nov 2003-2007	**Sharp et al 2007** Bioko Island, Equatorial Guinea	Window Exit Trap (WET)	Community-based (home owner)as stand alone	16 sentinel sites @6 (96 houses sampled monthly	59,307 trap nights
February 2009-Oct 2010	**Chaki et al** (Urban Dar es Salaam, Tanzania)	ITT and HLC	Community-based (community volunteers) with inbuilt Quality Assurance	615 houses sampled monthly	8171 trap nights

4.4 Discussion

Community-based use of the ITT with no supervision from the research team proved the most cost-effective and epidemiologically relevant way to monitor adult malaria vector mosquitoes and was also safer than the HLC gold standard method. Although this approach has low relative sensitivity per night of sampling, it is also by far the least expensive and allows far more intensive longitudinal sampling so that it is slightly more effective than even QA-HLC in terms of absolute sensitivity, cost-effectiveness and spatial extensiveness. Critically, the ability to conduct longitudinal sampling on a monthly temporal cycle that is sufficiently frequent to capture seasonal variation in vector density at hundreds of locations concurrently gives this implementation system epidemiological predictive value that traditional survey methods, relying on closely supervised research teams, did not even distantly approach (Table 4.3.3).

This CB survey achieved a spatial resolution of one trap-night sample per 0.27 km^2 every month and 0.93 km^2 every week across the 31 volunteers and their assigned wards. In demographic terms, this is equivalent to one trap night for every 5,848 residents per month or 21,739 residents per week. Such intensive and extensive monitoring of adult mosquito responds to the needs of the local UMCP larviciding programme because it is matched to the scales to which responsibility for applying larvicides is devolved so that gaps in coverage, sensitivity and quality of these activities can be identified and rectified. The distribution of adult mosquito sampling locations therefore encompassed the assigned target areas of every person responsible for larvicide application so that their individual personal performance can be evaluated objectively and independently, based on one or more observations each month. In spite of the proven efficacy of larvicides (Barbazan *et al.* 1998, Fillinger *et al.* 2003), the success of a larviciding program relies on the sensitivity of detection and treatment of all potential larval habitats by large numbers of widely-distributed staff managed in a decentralized way at ward level (Chaki *et al.* 2009, Killeen *et al.* 2002a). This spatially extensive, community-based surveillance with the ITT has demonstrated the potential for identifying malaria transmission hotspots on very fine scales (Table 4.3.3). Longitudinal CB surveillance with the ITT or any other practical, ideally more sensitive, alternative trapping technology may be a useful means for mapping residual vector populations and enable targeted control with supplementary vector control measures such as larval source management that complement LLINs or IRS. An ideal trap is presumably low cost, less bulk, easily transportable and preferably independent of electrical power.

Although various traps and survey platforms have been developed and implemented for trapping, monitoring and studying mosquito vectors of malaria and other disease in various parts of the world (Dusfour *et al.* 2010, Hoel *et al.* 2007, Mathenge *et al.* 2002, Moore *et al.* 2001, Obenauer *et al.* 2010, Odetoyinbo 1969,, Service 1977), currently declining malaria transmission levels (Ceesay *et al.* 2008, D'Acremont *et al.* 2010, Feachem *et al.* 2010, O'Meara *et al.* 2010, O'Meara *et al.* 2008) and mosquito densities (Russell *et al.* 2010) pose particular challenge to monitoring and evaluating disease trends. To date, mosquito vector surveillance has often depended on the use of conventional methods either under strict research-controlled settings or community-based platforms. Research-controlled studies are often limited in scope in terms of spatial and temporal coverage due to associated high running costs and therefore very expensive to maintain on scales large enough to detect the very fine persistent transmission levels and support decisive management of vector control activities. This is exacerbated by the limited number of expert personnel in most malaria endemic countries. Even when community based surveys have been used with conventional tools, the quality of unsupervised data collection has been a concern to most public experts. In this study, the ITT was used to sample mosquitoes at a much higher spatial resolution as an outdoor trap. In comparison with other recently reported surveys (Table 4.3.4), the use of ITT appears to be more user friendly and affordable because it operates less intrusively to house owners' privacy since it is set outside and therefore could be moved around to optimize spatial coverage. This is a necessary and crucial aspect of an idealized surveillance system and the present goal of malaria elimination/eradication makes this current platform epidemiologically relevant. Furthermore and probably more crucial is the question of data quality assurance, while all the survey platforms described in (Table 4.3.4) successfully engaged local communities in their operations, only the approach developed in Tanzania has inbuilt quality assurance mechanisms. Since the quality of health information data particularly in most developing countries is arguably questionable, survey systems equipped with quality assurance mechanisms as demonstrated in this study are of paramount importance, in order to generate reliable information that will support evidence based targeted vector control interventions.

Despite the advantages that the tent trap and community-based survey system appear to offer, both the ITT technology and the delivery system described here have significant limitations, some of which synergize negatively. The ITT has important limitations as an entomological and epidemiological surveillance tool because of limited sensitivity, particularly at high mosquito densities. The observation that this problem is exacerbated when used through the CB system presumably reflects our informal observations of the poor compliance by the CORPs with setting up and sleeping in the traps during wet season peaks of mosquito density when rain may enter the trap. This observation is a typical challenge of most unsupervised community-led disease surveillance systems. Moreover, the bulky nature of the trap makes it impractical for indoor use and therefore unsuitable for surveying the proportion of human exposure to mosquito bites that occurs indoors. Even for outdoor applications, the space requirements of the trap poses particular challenges in densely populated informal settlements in urban settings. Moreover, even with the predominantly flat topography of Dar es Salaam, the bulkiness of the trap makes it too heavy and difficult to be moved between sampling locations by one volunteer without at least a bicycle.

4.5 Conclusions

As the global malaria elimination initiative (Campbell 2008, Feachem *et al.* 2010, Greenwood 2008a, Greenwood *et al.* 2008, Roberts and Enserink 2007, Tanner and Savigny 2008) advances, spatially extensive longitudinal vector surveillance systems, such as the CB trapping system reported here, will become increasingly necessary to characterize sparse residual vector populations across large areas and for monitoring and evaluating impact of interventions upon them. In practical terms, we recommend that further advances with CB mosquito surveillance systems will require development of improved trap technologies that will ideally no longer require human bait. Such products should be more sensitive, less bulky, less expensive, and should readily trap the outdoor-biting, zoophagic mosquito species that increasingly dominate residual transmission across the tropics (Bayoh *et al.* 2010, Bugoro *et al.* 2011, Reddy *et al.* 2011, Russell *et al.* 2011a). Given that several experimental prototypes already exist that use synthetic odour mixtures as bait and which are highly efficacious for sampling a broad spectrum of mosquito species (Bernier *et al.* 2007, Krockel *et al.* 2006, Qiu *et al.* 2007, Smallegange *et al.*

2005, Smallegange *et al.* 2009), including some that representatively samples the taxa that attack humans (Okumu *et al*. 2010), we recommend that such evaluated trap designs can be adapted for the surveillance of a variety of mosquito-borne diseases including malaria, lymphatic filariasis and dengue fever.

CHAPTER FIVE

LANDSCAPES OF RESPONSIBILITY: EVOLVING OF ROLES AND RESPONSIBILITIES FOR COMMUNITIES AND INSTITUTIONS IN A LARVAL CONTROL PROGRAMME FOR MALARIA PREVENTION IN URBAN DAR ES SALAA, TANZANIA

This paper is in preparation for publication

as

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5.0 Abstract

Targeting mosquito larvae was regarded as a practical means to reduce malaria in cities in the first half of the 20th century but fell out of favour because it demands considerable manpower, entomological expertise and institutional oversight. Initiated by the Dar es Salaam City Council in Tanzania, the UMCP evaluated the effectiveness of community-based systems for applying microbial larvicides to aquatic larval habitats to reduce malaria prevalence as a routine municipal service delivered by paid volunteers known as community-owned resource personnel (CORPs). Analysis of CORPS activities suggests that public health governance is framed within a nested set of spatially-defined relationships between residents, government, research institutions and mosquito populations that build upward from neighbourhood to city and national scales. The UMCP developed a clear hierarchical structure nested within the vertical management system of this primarily community-based programme with clearly defined lines of responsibilities across the various relevant scales. Although the UMCP started off rather chaotically with the roles of the various research and implementation partners ambiguously assigned, the central coordination role played the city council enabled institutionalization of strengthened management and planning, improved community mobilization capability, and capacity to exploit national and international funding systems. Strong City Council ownership, coupled with catalytic donor funding and technical support from expert research partners, enabled establishment of a sustainable implementation program funded by the national Ministry of Health and Social Welfare, overseen by the National Malaria Control Programme and implemented by the City and Municipal Councils. Complementary research, monitoring and evaluation activities are now

separately funded through competitive international research grants and implemented by national research institutions so that technical expertise in the region has been strengthened through postgraduate training and career development for more than a dozen Tanzanian and Kenyan scientists and practitioners.

5.1 Background

Urban malaria control has a long history across the world and in Africa particularly, dating back almost 100 years (Castro *et al.* 2004, Clyde 1967). Combinations of environmental management, larviciding, mosquito-proofing houses, personal protection measures, and antimalarial drugs were used simultaneously before World War II for malaria control (Keiser *et al.* 2005, Lindsay *et al.* 2002, Utzinger *et al.* 2002b). Urban malaria control in Tanzania during the 1960s relied heavily upon larviciding and community-implemented environmental management, such as drainage and habitat filling, resulting in malaria transmission that was considered to be of limited magnitude (Clyde 1961a). However, these methods were abandoned for many years as they were considered to be too logistically complex (Feachem *et al.* 2010, Walker and Lynch 2007) in comparison with targeting houses with indoor residual spraying (IRS) of houses with insecticides (Kouznetsov 1977, Mabaso *et al.* 2004) and, later on, with insectide-treated nets (ITNs) (Lengeler 2004). Recently, however, it has been recognized that these approaches have fundamental limitations and are not, in themselves, sufficient to eliminate malaria (Griffin *et al.* 2010). Furthermore, there has been a shift in thinking associated with changes in human population dynamics, specifically increasing urbanization and rural-urban population migration (Hay *et al.* 2005, Keiser *et al.* 2004, Robert *et al.* 2003) as well as changes in the mosquito populations through increased outdoor feeding behaviour (Braimah *et al.* 2005, Bugoro *et al.* 2011, Govella *et al.* 2010b, Oyewole and Awolola 2006, Pates and Curtis 2005, Russell *et al.* 2011a) and resistance to insecticides (Hemingway and Ranson 2000, Kelly-Hope *et al.* 2008, Nauen 2007). There has therefore recently been a revival of interest in implementing and evaluating traditional larval source management methods for malaria prevention to complement the existing priority interventions of NMCPs in malaria endemic countries (Fillinger *et al.* 2009, Killeen *et al.* 2003, Killeen *et al.* 2002b, Mukabana *et al.* 2006, WHO 2004, WHO 2006a). It is increasingly acknowledged that community involvement can improve coverage, equity, sustainability, efficiency and effectiveness of a range of public health generally, and vector control interventions in particular (Heintze *et al.* 2007, WHO 1983, Winch *et al.* 1992). However, there is a clear need to better understand the practices of governance that larval control necessitates and the collaborative potential that exists between malaria-afflicted communities, research institutions and all levels of local and national government. The highly-localized task of detection and management of mosquito larval habitats traverses public and private landscapes at all spatial and governance scales (Killeen *et al.* 2006c, Mukabana *et al.* 2006) so larval control of malaria vectors is as much a civic as a governmental or scientific goal.

Since the World Health Organization (WHO) declared that “the people have a right and duty to participate individually and collectively in the planning and implementation of health care” (1978), community-based organizations have become a central feature for global public health governance (WHO 1978). Participatory planning is now regarded as the *sine qua non* of successful health service delivery, and of development more broadly; without measures to enhance local capacities and ensure community ownership, interventions usually fail and services remain under-utilized or misused (Hongoro and McPake 2004, WHO 2006b) However, as a number of scholars have argued, the scope and extent of participation remains undefined (Rifkin *et al.* 1988). Many have criticized utopian assumptions about the capacity of the 'community' to provide a panacea for a number of entrenched economic, social and health problems (Bhattacharyya 1995, Leach *et al.* 2005). Others have questioned whether practices of 'participation' might; in fact, serve to diminish the democratic character of development, by circumscribing the ways in which citizenship is perceived (Cooke and Kothari 2001, Mosse *et al.* 2001).

This research examines a city-level larval control programme initiated over the last eight years in Urban Dar es Salaam, Tanzania to understand better how scientific research relates to and can contribute to public health governance. The overall goal of the contemporary Dar es Salaam UMCP, formulated at a stakeholder's meeting in 2003, is to reduce the incidence of malaria through the identification and treatment of the breeding grounds of *Anopheles* mosquitoes so that vector populations are substantially suppressed (Mukabana *et al.* 2006). Designed by a consortium of local, national and international partners, and initiated by the Ilala Municipal Council – one of three municipalities that comprise Dar es Salaam – the programme aims to integrate mosquito larval control into routine municipal services (Mukabana *et al.* 2006). Between 2004 and 2009, the UMCP expanded across a substantial portion of the city, an area that includes fifteen wards and roughly 614,000 of the city's 3 million residents (Dongus *et al.* 2011a). At this scale, the UMCP is not only an operational research programme, but also a public health service of considerable size. The combined research and implementation activities have been supported with funding from a variety of sources – the Bill & Melinda Gates Foundation, the United States Agency for International Development, the Innovative Vector Control Consortium, Valent Biosciences Corporation and the Wellcome Trust – to develop and evaluate sustainable implementation systems for regular surveillance and treatment of mosquito populations and breeding habitats (Fillinger *et al.* 2008, Mukabana *et al.* 2006). The community based mapping (Dongus *et al.* 2011a, Dongus *et al.* 2007) and weekly mosquito larval surveys (Fillinger *et al.* 2008) of the UMCP were designed to determine whether the application of larvicide has been comprehensive and to identify areas that have been missed. The UMCP situates malaria control and associated operational research within the routine system for municipal service provision by delegating the responsibility for larval control to community members known as Community Owned Resource Persons (CORPs) appointed through Street Health Committees across the city (Dongus *et al.* 2007, Fillinger *et al.* 2008, Mukabana *et al.* 2006, Vanek *et al.* 2006).

The UMCP's emphasis on generating local capacity and building partnerships between communities, local government and researchers (Fillinger *et al.* 2008, Mukabana *et al.* 2006) is, not only a central component of international development and public health practice, but also a pillar of globally accepted integrated vector management development strategy (Anonymous 2001a, Killeen *et al.* 2006c, Townson *et al.* 2005, WHO 2004, WHO 2006b). In Tanzania, these participatory approaches are further rooted in governmental practice and cultural norms. Following independence, under Julius Nyerere's government, popular participation became a central instrument for socio-economic transformation: "if development is to benefit the people, the people must participate in considering, planning and implementing their development plans" (Nyerere 1967). Much scholarship has examined how that political legacy has inflected current understandings of participation (Jennings 2007, Samoff 1979) and the traction of development programmes premised on community ownership (Green 2003, Jennings 2007).

This paper explores how public health governance is articulated through scientific protocols, development practice and the specific political history of Tanzania. Our empirical focus is the encounter between CORPs, programme managers, scientists and residents and the forms of responsibility that emerge when research practices are embedded into the fabric of urban living. After a brief note on methodology, paper is divided into five sections: We begin by describing the history of larval control from the first large-scale attempts at 'species sanitation' in the early part of the 20th century to latter-day applications of that strategy in Dar es Salaam. Of particular interest here is the relationship between the technical demands of larval control and the institutional settings in which these activities take place: in other words, how the task of eliminating the larvae of *Anopheles* mosquitoes is shaped by the relationships between residents, research institutions, and governmental bodies – at the, community, municipal, city and national level.

In the second section, we contextualize these roles, relationships and activities by examining the political culture of Dar es Salaam. Tracking the multiple meanings of participation as a culturally valued development and nation-building strategy, and an emphasis of current global health policy (Marsland 2006), we situate the UMCP within its specific institutional setting. Our aim is to not only understand the scope and potential of enrolling community members in controlling proliferation of mosquito larvae (Dongus *et al.* 2010), but also to better understand the ways in which those capacities are shaped by the institutional forms and administrative practices designed to facilitate them (Green 2010).

It is within this historical framework that we return, in the third section, to the UMCP and consider the efforts made to transform Dar es Salaam into a space of public health intervention and, ultimately, an object of community ownership. In this analysis of the daily, front-line activities of UMCP, we detail the day-to-day work of the CORP and the multiple roles his or her work entails – as, at once, a compensated research participant, an informal labourer, a voluntary public servant and a member of the serviced community. We outline the constraints and capacities of those multiple, and at times conflicting, roles for the stable integration of scientific resources into local research and implementation institutions (Kelly *et al.* 2010).

In the fourth section, we reflect on the alignments, inter-linkages and nested spatial scales of global science, municipal administration, urban life and the ecologies of both pathogen and vector that are illuminated by the UMCP. We argue that by scrutinizing these processes and contexts, we can advance the discussion on how participation in public health, specifically urban mosquito control is and should be managed. By looking at the spatial, administrative and social reconfigurations that are required to manage the proliferation of mosquito populations, this paper aims to extend our appreciation of how the city animates and is animated through research and action.

To conclude, we summarize the progress towards development and characterization of optimal models for sustained, effective community-based larval source management in Dar es Salaam. In this fifth, final section we review lessons learned from the successes and remaining challenges of the evolving, iterative "learning by doing" (Ross 1902, Ross 1911) exercise that is the UMCP.

5.2 Methodology

Our data are drawn from participatory observations made while working with or for the UMCP over a period of 8 years – helping to design larval control and surveillance protocols and to implement the program with community volunteers. Structured, open-ended interviews were conducted with sixty-four CORPS, ten members of the management team and eight investigators from the supporting scientific team. The ten management team members comprised of 5 ward supervisors initially hired as CORPs, others included 2 municipal malaria control inspectors and 1 municipal malaria control coordinators employed by the city council as health officers, 1 City mosquito surveillance officer and the 1 City mosquito control coordinator (Fillinger *et al.* 2008). On the other hand the eighty scientists included 4 MSc and 2 PhD students as well as 2 senior investigators. While the content of interviews varied, they all focused on description of duties to and experiences of the programme, and how these changed as the UMCP sources of funding and institutional structure changed over the years. Finally, a series of unscheduled guided walks were also undertaken with twenty-three of the CORPs as they performed routine larval habitat surveillance and prepared their daily reports, to achieve a better understanding of the day-to-day operational challenges of larval control. The coauthors worked together on analyzing this ethnographic and interview data, focusing on issues relating to responsibilities for the programme and experiences of collaboration. This contemporary set of observations supported by a close reading of relevant anthropological literature relating to public health, to mosquito and malaria control and to the governance history of Dar es Salaam.

5.3 Larval Control Logic

> He [Robert Koch] lays particular stress on the opinion of an unnamed ‘expert engineer’ that the most prolific *Anopheles*-producing area, the swamp at the mouth of Gerezani Creek is undrainable. Let me here remark, by the way, that a survey showed this swamp to be drainable and that when I left Dar es Salam the creek and swamp were practically free from mosquito larvae, as a result of clearing the creek and ditching, which was done only on a small experimental scale because of the absence of funds (Orenstein 1914).

Dar es Salaam has a long history of malaria control. A.J. Orenstein, an American doctor with extensive experience in public health campaigns, had been hired by the Rand Mining Company to advise on the sanitary conditions of South African mines (Packard 1989). His contribution to the reduction of malaria during the construction of the Panama Canal earned him an invitation from the Governor, of what was then German East Africa, to institute a campaign in Dar es Salaam. He reported his findings in a short article (Orenstein 1914) which constituted a rebuttal to another published in the previous issue (Henson 1914), which argued that despite excellent results of anti-mosquito campaigns in places like the Panama Canal, in other places it could not be expected to reduce, let alone eliminate, *Anopheles*, because of unstable landscapes, vector species and climatic conditions. Rather than “wait for the development of our agricultural lands” (Henson 1914) the article that prompted Orenstein’s response recommended that another method should take precedence – the early diagnosis and rapid treatment of those infected (Henson 1914).

Orenstein’s report begins by describing the city’s racial geography: “The town is divided into two settlements: the white quarter, situated near the beach, and a native quarter further inland” (Orenstein 1914). Though a common tactic of colonial urban planning, Orenstein’s disdain for segregation as a policy for disease control is apparent in the comprehensive survey he provides of the city’s vector breeding-grounds (Anderson 2002) His focus rests squarely on the vector which bred within and moved across neighborhoods, regardless of the race of their residents. In a similar vein to his research in Panama, which provided an in-depth summary of the specific natural and man-made causes for malarial outbreaks (Gorgas 1915, Le Prince 1916), he details the entomological landscape of Dar es Salaam, linking topographical features with material conditions, marshlands with roof gutters, permanent pools in the native quarter and the sewage tanks installed in European Houses (Orenstein 1914). The report concludes with an experiment. He compares the decrease in parasite levels among “negro pupils of the Dar es Salaam Trades School who live in dormitories and do not come into contact with the outside population” (ibid 1914: 1933) (Orenstein 1914) who were treated with quinine over the course of eighteen months, with the infection rate of those living in the vicinity of a Karavanserai Pond, a permanent pool at the centre of the native area that, upon Orenstein’s recommendation, was cleared of vegetation and treated with oil every ten days. The study showed a greater reduction in disease for the latter, even without having completely rid the area of *Anopheles*. [1]

That outcome did not merely demonstrate the public health potential of larval control; it directly contradicted the methods advocated by the famous German bacteriologist, Robert Koch. Following Charles Laveran’s discovery of *Plasmodium* parasites in the blood-slides of afflicted

[1] Ornestein writes: “it is also to be noted that the control of the one breeding area did not by any means eliminate anophelines from the vicinity which the subjects were drawn.” (ibid. 1933).

patients, Koch argued that the best approach to eliminate malaria would be to reduce the infection in humans. For Koch, malaria was, first and foremost, a clinical problem. Through mass treatment of symptomatic patients – particularly semi-immune indigenous African children, who, from the point of view of white settlers, represented a dangerous reservoir of infection – Koch believed transmission could be reduced across the population. Under Koch's direction, Dar es Salaam became the site of the most extensive quinine distribution programme in Africa. Introduced in 1901, the programme involved taking blood slides of all Africans working in the white quarter, and giving those found infected a routine dose of chemotherapy (Curtin 1985).[2] This systematic process, Orenstein points out, focused primarily on servants and artisans, while highly mobile traders, porters and agricultural labours were left untreated (Burton 2003). Further, the challenge posed by labour migration to prophylactic treatment may well be secondary to that introduced by the mobility of *Anopheles* (Killeen *et al.* 2003, Service 1997). After implementing Koch's method for more than a decade, the incidence of malaria in Dar had not changed significantly. For Orenstein, in contrast, there was no malaria without *Anopheles*; his experiment, he argued, clearly demonstrated why this was the case. [3]

Orenstein's report underscores two key conditions of larval control. The first is the necessity of intimate ecological knowledge. In Panama, Orenstein worked under the supervision of William Gorgas, a Surgeon in the U.S. Army who had overseen the elimination of yellow fever in

[2] For a detailed discussion of Koch's quininization program, see Curtin 1985: 597–598.

[3] To some extent this approach to the vector stood in contrast to an approach that aimed to improve the conditions of life more broadly. For instance, according to Italian entomologists, malaria was primarily a social disease, "connected with the economic and political life of the people who inhabit the regions where it dominates" (Celli 1900:2 cited in Packard 2007:111). This approach, termed 'bonification', was enthusiastically taken up by Mussolini, who sought to reduce disease incidence through better housing, agricultural innovation and economic reforms (Farley 2004).

Havana. Gorgas was the pioneer of a method, which came to be known as ‘species sanitation’, that entailed a complex micro-cartography of intervention – draining marshes, cutting grass by river banks, covering pit latrines and garden wells, oiling ponds, filling ditches with concrete and footprints with sand (Packard 2007, Spielman and D'Antonio 2001). Characterized by what Shaw and colleagues (Shaw *et al.* 2010), termed ‘immanent horizontalism’, species sanitation tracked the life cycles, feeding behaviours and habitats of mosquito populations within a defined area. It demanded detailed and up-to-date knowledge of breeding sites as they dynamically emerged over time, whether in swamps or in the backyards of government officials (Farley 2004). Koch’s theories fell short, in part, because Orenstein argued, they relied “on the opinion of an unnamed expert engineer” (Orenstein 1914) to contextualize conclusions drawn from the laboratory, as opposed to drawing on direct experience of Dar es Salaam’s city streets (Kohler 2002).

Although entomological knowledge was critical to the systematic identification of breeding grounds, their destruction required both social and political capacity (Ross 1902). His strategy, which inspired Gorgas and a generation of public health authorities, outlined in meticulous detail how to coordinate a larval control campaign conducted with limited resources (Ross 1902). He stressed the advantages of using local labour, not simply because it was cheap, but because it ensured access into the homes of local residents. No entomological training, no matter how advanced, could prevent the misunderstandings that might arise while searching through someone’s trash (Ross 1902). For Ross, larval control depended as much upon local resident commitment as it did on scientific expertise:

> All this looks very formidable on paper. It is not so in reality. A very few men working day after day will do wonders in the course of a few months. The great thing is to make a beginning: not to form counsels of perfection, not to measure means with ends, but simply to set to work with whatever force there is available, however small it may be. A single private citizen can eradicate malaria from a whole town. In an enterprise of this nature, the means grow as the work proceeds (Ross 1902).

Orenstein also stressed the pragmatic nature of larval control: even his small-scale experimental intervention made a difference. Further, he echoes Ross's emphasis on the necessity of political will and administrative support. At the conclusion of his report, he notes that his efforts "were rendered almost sterile by passive and active resistance, lack of funds, 'red tape' in volumes beyond the comprehension, I fear, of the average American" (Orenstein 1914). Successful larval control depended on a pervasive and persistent administrative presence; whether in the form of colonial garrisons or paramilitary forces, "a genuine campaign," Ross noted, "…must always be a permanent concern of the State" (Ross 1911).

Despite Orenstein's doubts about the commitment of the German colonial administration, by the time his article was printed a series of sanctions had been passed to reduce mosquito-density in the city. Residents who failed to empty water daily from receptacles on their properties – including tin cans and coconut shells –were issued fines (Clyde 1967). Those who could not pay were imprisoned. When Tanzania became a British Protectorate after World War I, these and similar measures were applied in earnest. A section of Township Rules entitled the "Extermination of Mosquitoes Ordinance", applicable to all small towns and settlements, elaborated rules for rice and potato cultivation and demanded that property holders take the necessary steps, at their own expense, to prevent mosquito breeding on their land (Clyde 1967). Through the deployment of the Royal Army Medical Corps, the British also carried out a wide range of vector-control strategies, including comprehensive drainage work, stream straightening and livestock surveillance so that cattle could not enter and destroy the drainage systems (Castro *et al.* 2004).

Conducted within the everyday spaces of urban life, larval control inevitably overlapped with sanitation, public education, urban planning and health surveillance. Despite Ross's conviction that "a single private citizen can eradicate malaria from a whole town," (Ross 1902) larval control required pre-existing infrastructure and considerable manpower. In Argentina, for instance, the director of the malaria control program, Carlos Alvarado, formalized Ross's brigades into 'foci patrols' – highly local, flexible and experiential larviciding teams, which drew on the militarized populism introduced by Juan Perón (Carter 2007). In the 1930s and 1940s, Fred Soper would make foci patrols famous in the elimination of *Anopheles* mosquitoes from Brazil and Egypt, after highly virulent *falciparum* malaria epidemics had ravaged large tracts of both countries (Killeen 2003, Killeen *et al.* 2002b, Shousha 1948, Soper and Wilson 1943). Integrated malaria control programmes that targeted *An. gambiae* and *An. funestus* by applying environmental management in the form of vegetation clearance, modification of river boundaries, draining swamps, oil application to open water bodies and house screening were highly successful at the Roan Antelope copper mine in Zambia (Utzinger *et al.* 2001, Watson 1953). The program was launched in 1929 and implemented for two decades until 1949 across the entire copper mining communities in the Copper-belt of Zambia and achieved dramatic reductions mortality, morbidity and other malaria incidence (Utzinger *et al.* 2001, Watson 1953).

But by the late 1940s, Soper and Alvarado had abandoned foci patrols in favour of a new weapon that dramatically altered the landscape of malaria control: an insecticidal residual spray for killing adult rather than aquatic stage *Anopheles* (Gladwell 2002). First synthesized in the late 1930s Dichloro-Diphenyl-Trichlororethane (DDT) killed adult mosquitoes at low concentrations and continued to kill them over long periods of time. World War II provided the impetus and capacity for large-scale production of the chemical, and afforded an irresistible justification for its rapid introduction (Garrett-Jones 1964, MacDonald 1957, Russell 2001). Applied to the wall of a house, DDT could keep killing mosquitoes for months. It also rendered superfluous any extensive ecological and entomological research prior to intervention. DDT levelled the differences between towns and nations, creating the conditions under which malaria could be attacked as a universal biological entity. Thus, by the time the WHO issued its *Global Malaria Eradication Program* (GMEP) in 1955, its rationale was drawn from broadly generalized epidemiological models (Garrett-Jones 1964, MacDonald 1957), rather than detailed entomological reports (Kelly and Beisel 2011). Soper had been convinced that “man has it in his power to eradicate any mosquitoes anywhere”, but the dream of eradication did not include Africa (Gladwell 2002, Litsios 1996, Trigg and Kondrachine 1998). Where transmission rates are high and stable, the majority of experts argued that the large-scale and rapid application of DDT was not only unlikely to succeed but could exacerbate matters in the long run by interrupting naturally acquired immunity (Snow and Marsh 2002). In spite of these concerns, or rather because of them, Tanzania once again became the site of an experiment, this time in the Pare-

Taveta region (Dobson *et al.* 2000). The Pare-Taveta scheme involved the mass-spraying of dieldrin on the walls of every inhabited house within a strip of land along the Kenyan border one hundred miles long and twenty miles wide. In 1959, after four years and five rounds of spraying, mosquito populations and malaria transmission (and many other forms of domestic life, including chickens to cats) had been dramatically reduced, but not enough to interrupt transmission (Draper and Smith 1957, Draper *et al.* 1972, Kouznetsov 1977). Similar observations from a large-scale trial in Nigeria (Molineaux and Gramiccia 1980), combined with careful review of existing programmatic monitoring data (Kouznetsov 1977), confirmed that while indoor residual spraying is a potent malaria control tool, it cannot eliminate malaria from most equatorial African settings (Griffin *et al.* 2010).

The gradual acceptance of this accumulated evidence slowly shifted the emphasis of policy back towards national, and even local-level, control schemes (Yhdego and Majura 1988). In Dar es Salaam, larval control remained a central method throughout the 1960s and early 1970s. Reduction of malaria incidence was central to Nyerere's plan for national development, a strategy which linked improvements in public health infrastructure to economic growth.[4] With support from the East Africa Malaria and Vector-Control Unit, an organization created to conduct regionally-relevant operational research (Beck 1973) and enhance Africa's scientific capacity, Nyerere's health initiatives had considerable impact both in Dar es Salaam and nationally. In 1971, the WHO East Africa *Aedes* Research Unit experimented with an integrated vector control programme in collaboration with the Dar es Salaam City Council (Bang *et al.* 1975). By 1973, the malaria transmission rate in Dar es Salaam reached its lowest point in

[4] Inspired by China's barefoot doctor programme, Nyerere created a network of rural centres, and ultimately, relocated the rural population to facilitate access (Hsu 2007).

recorded history, ironically just at the moment when Tanzania's deepening economic crisis made environmental management programme economically unfeasible. As a result of the pressures of the International Monetary Fund to rein in the country's budget deficit, spending on health was cut in half, the National Malaria Control Program was discontinued, and chemical treatment of the diseases through pharmaceuticals, overwhelmingly chloroquine, became *de facto* the sole anti-malaria intervention available. In the 1980s, *P. falciparum* resistance to chloroquine appeared in coastal Tanzania and Kenya and soon spread across Africa. In Dar es Salaam, the density of *Anopheles* soared (Bang *et al.* 1975, Yhdego and Majura 1988).

It was not until 1988 that the city once again became the site of a large-scale malaria control intervention. The Government of Japan sponsored an integrated urban malaria control programme centred on larval source management. Over the course of eight years, the Japan International Cooperation Agency (JICA) donated resources, equipment and technical expertise amounting to roughly US$21 million at 1US$ to 590.74TSHs in 1996, equivalent to about US$56.9 million in 2011 at an exchange rate of 1US$ to 1600TSHs. Despite its successes, for instance in rehabilitating drainage infrastructure (Castro *et al.* 2004), the programme never became sustainable. In an interview, one of the municipal officials involved in the project attributed this failure to the architecture of the programme management: in accordance with Japanese government policy, Japanese advisors rotated every two years, advising Tanzanian partners on the techniques of vector control but neglecting institutionalization of its essential surveillance, management and planning processes (Castro *et al.* 2004). Although this JICA-supported programme has also been referred to in previous publications as the "Dar es Salaam UMCP" and even as a "contemporary UMCP" (Castro *et al.* 2004), to avoid confusion, here we apply such terminology only to the currently ongoing programme in Dar es Salaam which was deliberately reconstituted as a completely new entity to specifically learn from, rather than repeat, these mistakes (Fillinger *et al.* 2008, Mukabana *et al.* 2006).

Though not sustainable as a long-term programme of vector control, Japan's intervention produced a fine-grained cartographic profile of the city. Aerial photographs and derived stereoscopic maps documented the city's ecology and epidemiology, complementing records dating back almost a century. In an intriguing resumption of the work that Orenstein had conducted many decades earlier, the program's spatial analysis of the urban environment enabled execution of a spatially targeted larval control campaign. However, the program failed to make use of local administrative resources in implementing the program (Castro *et al.* 2004). "Community participation," they note, "turned out to be much more difficult to achieve than was anticipated" (Castro *et al.* 2004). In the following section, we explore why this was the case. By elaborating the political history of Dar es Salaam, we will explore how changes in municipal governance have shaped the civic capacities of the city's residents to participate in disease control.

5.4 Ward Councils

Dar es Salaam was declared a municipality in 1948. With an estimated size of 1,350 square kilometres, in 1948 Dar es Salaam's population was estimated to be only 69,000 and growing at a modest pace of 2.6% .This municipal status coincided with a drastic shift in British colonial policy, from ignoring African urban populations to encouraging their participation in government

(Brennan and Burton 2007). Up to this point, the city had been generally regarded as a white settlement serviced by a migrant labour force – a misconception that Orenstein's report had already sought to correct. As officials finally came to grips with the rapid pace of urbanization, a series of initiatives were put in place to stabilize employment and orient the development of an African civil society (Burton 2005). One central component of this new colonial scheme was the establishment of Ward Councils to represent the interests of local residents from these administrative and geographic subunits to the Municipal Council. In contrast to the pre-existing communal associations, which officials dismissed as 'tribal', the councils were modern institutions, vehicles for transforming 'tribesmen' into civic-minded townsmen (ibid. 346).[5]

These efforts to involve Africans in municipal government were largely unsuccessful, because the Ward Councils were given negligible financial or administrative power (Iliffe 1979). Political mobilization would emerge outside of, and ultimately in reaction to, colonial supervision, first in the form of labour unions and ultimately through the Tanganyika African National Union (TANU). Ultimately the Ward Councils inspired civic consciousness, but not the kind sought by the colonial authorities; as instantiations of the deep inequality between the different racial communities present in the city, they served to catalyze nationalist sentiment (Pratt 1976).

When Julius Nyerere came to power 1961, one of his central goals was bolstering the administrative powers of local government. He introduced district, urban and municipal councils

[5] This shift to a modern and multi-ethnic identity stood in contrast to the political emphasis placed on the notion of tribe by the Germans. While 'tribal elders' or chieftains provided the means to indirectly administrate rural areas, they were also critical actors in the political ecology of towns, as under German law, tribes were responsible for burying their dead (389-390).

between 1962 and 1963 (Mukandala 1998) before officially abolishing these in 1972 and 1973. This was a move towards decentralization at which point district development councils (DDCs), the executive branches of the central government were established (Max 1991). Eager to distance the newly independent state from the political order of a colonial past, Nyerere abandoned the distinction between bureaucracy and politics and filled district-level positions with TANU chairmen (Picard 1980). Initially, the politicization of the Councils was intended to instill commitment to the socialist cause. Through the philosophy of *Ujamaa*, Nyerere and his government aspired to liberate Tanzania from chronic underdevelopment by righting the imbalance between rural and urban development.[6] Mass participation and self-reliance were the tools through which Tanzania would be transformed into a modern, egalitarian society consistent with traditional African values. Nyerere pursued drastic policies to advance this vision, including most prominently, 'villagenization' – the forced relocation of rural populations to organized sites of cooperative production. As a symbolic gesture of shared purpose, he moved the administrative capital from Dar es Salaam to Dodoma, a less cosmopolitan, but more appropriately 'African' town (Pratt 1999).

Nyerere's development strategy quickly encountered problems and Dar es Salaam remains the *de facto* capital today where most national government ministries are still headquartered. His efforts to restructure agricultural production at the expense of investments in large-scale industry ultimately impoverished the country. Moreover, socialist economic policies resulted in state-run

[6] The literal meaning of *ujamaa* is family-hood. For Nyerere its use meant that "for us socialism involves building on the foundation of our past, and building also to our own design…by emphasizing certain characteristics of our traditional organization, and extending them so they can embrace the possibilities of modern technology" (Nyerere [1968] 2002: 133)

monopolies and much-abused power structures that disempowered and discouraged commercial initiative all the way from the small farmer up to large scale industries. This process is most clearly demonstrated by the agricultural nationalization scheme and consequent collapse of most grass-roots co-operative unions (Pratt 1999). To increase financial oversight of developmental processes, Nyerere introduced in 1972, his so-called 'decentralization policy' that replaced local government with a network of district development councils (DDCs) under the supervision of regional and district officers (Picard 1980). In theory the system was aimed at coordinating grass-roots programmes, but in practice it served to shift decision-making powers for development in rural districts from bottom up democracy back to the central government which remains, to this day, a vehicle for top-down autocracy. In his detailed analysis of local politics in Moshi during the late 1960s, Joel Samoff commented on the impact of this bureaucratic approach to development (Samoff 1973):

> The poor articulation of the links between the levels in development planning and the bureaucratic imperative to avoid responsibility where rules and precedents were not clear, function to nurture a tendency to shift decisions to higher levels and thus to limit local participation in development planning (1973: 97).

Many scholars have pointed to the post-colonial recapitulation of the centralist tendencies of the colonial state, a continuity that ultimately eroded the new state's capacity to enrol people in nation-building projects (Ferguson 1994, Scott 1998). In Dar es Salam, the 1972 policy revisions gave the City Council control over the DDCs, whose budget now depended entirely on the national treasury. The government's bias against urban areas and the corresponding re-distribution of funding to rural councils led to a deterioration in urban services and infrastructures, including water and power provision, waste removal, road maintenance and malaria control (Kironde and Lusugga 1995).

Dar es Salaam's deteriorating economic conditions, coupled with inefficiency and gross corruption of the DDCs (Max 1991, Pallotti 2008) led to the reinstitution of elected ward and district councils in early 1980s. But, without financial resources or trained personnel, ward councils and district-level authorities could do little to improve service provision (Kyessi 2005). As the economic crisis became further entrenched and structural adjustment measures were put in place, locally organized groups often took responsibility for the public services that the state no longer could provide (Lewinson 2007). Once rejected as contrary to the spirit of *ujamaa*, informal, unofficial systems of economic activity and infrastructure provision filled the gaps left by the state and mitigated the deterioration of urban life. As Mari Ali Tripp suggests, 'the resiliency of society and its ability to reproduce itself with considerable autonomy from the state is one of the reasons the entire fabric of society did not fall apart during the unprecedented hardship' (Tripp 1997).

In 1996, efforts were again made to formalize civic resource management through decentralized planning. Following a National Conference, 'Towards a Shared Vision for Local Government in Tanzania', Dar es Salaam was restructured into a multi-tiered governmental body, with the City Council at its apex. Three municipal councils, namely Ilala, Temeke and Kinondoni function as administrative intermediaries, while 73 wards (*Kata* in Swahili), 185 neighbourhoods (singular *Mtaa*, plural *Mitaa*), and >3000" ten-cell units (TCUs) or *Mashina* at its base. While the municipal and ward executive officers are appointed and paid by the city authority, the council members are paid by the city authority but elected by the residents in their respective wards. *Mtaa* leaders are elected by residents and work on a paid but voluntary, casual basis. They take responsibility for monitoring land development and organizing residents to perform basic and small-scale public health and maintenance tasks across their respective TCUs. The TCU is also equipped with a representative leader known as an *Mjumbe*, who, like the *Mtaa* leader, is elected by household members living within the cluster and works on a voluntary casual basis. By virtue of being closest to the community, such TCU leaders are expected to mobilize resources (human and capital) from among the residents and inspire collective action (Gibson *et al.* 2000).

The attempts to reduce the role of central government in the post-Nyerere era have been often connected to donor conditionality. While the vocabulary of 'self-reliance' and 'participation' remains, these terms no longer belong exclusively to a nationalist ethic, but rather describe a broader commitment to 'good governance' – i.e. to the efficient completion of specific projects in line with the performance standards of local, national and international funders (Krause 2010). The distinct roles of employed district officials and volunteer local leaders reflect the assumptions of contemporary development funders that participation is best done through local associations endowed with a significant degree of autonomy (Dill 2009).

Returning to the question with which we began this section – the particular challenges of community participation in disease control – several themes emerge from this preliminary analysis. First, our brief sketch of Tanzania's colonial and postcolonial history suggests that 'participation' is a complex and highly resonant term signifying both self-governance and the provision of labour. Second, an analysis of infrastructure in Dar es Salaam indicates that the particular spatial scale of civic engagement depends on distinct political formations. For instance, in light of the former role of the wards as vehicles for the central government, one might question the degree to which popular engagement in them overlaps with, or runs counter to, municipal units of administration (Dill 2010). Thirdly, it is clear that these formations and relationships are not fixed but have changed over time, often in ways other than those intended, and remain dynamic today as Tanzania society, government and institutions continue to evolve.

In the following section, as we return to the UMCP, we will consider the effects of this institutional history on the organization of public health practices at the municipality level. If, as Ronald Ross argued, "a genuine campaign must always be a permanent concern of the State," the question that follows is: How does Dar es Salaam's political infrastructure configure concern with health and malaria control? And furthermore, what role does the technical practice of larval control play in addressing and sustaining that concern?

5.5 Origins and evolution of a community-based malaria vector control programme for modern Dar es Salaam

5.5 Institutional roles and responsibilities

With almost a century of relevant historical experience, a reformed and decentralized health system (Harpham 1995, Harpham and Few 2002), and the specific inclusion of larval source management for the city as policy in the National Malaria Medium Term Strategic Plan for 2002-2007 (MOH 2002), Dar es Salaam and its three constituent municipalities councils were in a strong position for developing and evaluating community-based integrated vector control programme (Mtasiwa *et al.* 2003, Mukabana *et al.* 2006) at a time when such approaches had just returned to the scientific agenda (Killeen 2003, Killeen *et al.* 2002a, Utzinger *et al.* 2001, Utzinger *et al.* 2002b). The health sector reforms of the 1990s in Tanzania were geared at empowering the district and municipal health services and their constituent communities in management and decision making (Anonymous 2003a, Mtasiwa *et al.* 2003). Furthermore, the decentralization of the various operational processes at the municipal councils gave the various municipal bodies, including the Municipal Medical Offices of Health (MMOHs), autonomy in their functioning and responsibility to answer directly to their respective municipal health boards. These municipal health boards in turn are mandated to represent community interests and report to the municipal directorate rather than to the national Ministry of Health and Social Welfare. These reforms emphasised bottom-up management of health services and coincided with an international call to better understand and manage the effects of rapid urbanization upon health (Knudsen and Slooff 1992, WorldBank 1993). Consequently, the Urban Health Project (UHP) was initiated in Dar es Salaam in the early 1990s with the support of the Swiss government (Harpham 1995, Harpham and Few 2002). This project focused particularly on low-income urban populations and aimed at strengthening the health system as a whole. The implementation of UHP integrated well with local government reforms and was characterised by a strong community participation component (Harpham and Few 2002). It was out of this framework that the UMCP was born with a defined goal of staging community-based malaria control through larval source management (Mukabana *et al.* 2006). Overall, community participation ultimately became the most important strategy for implementing the UMCP and delivering larval source management on a sustainable basis.

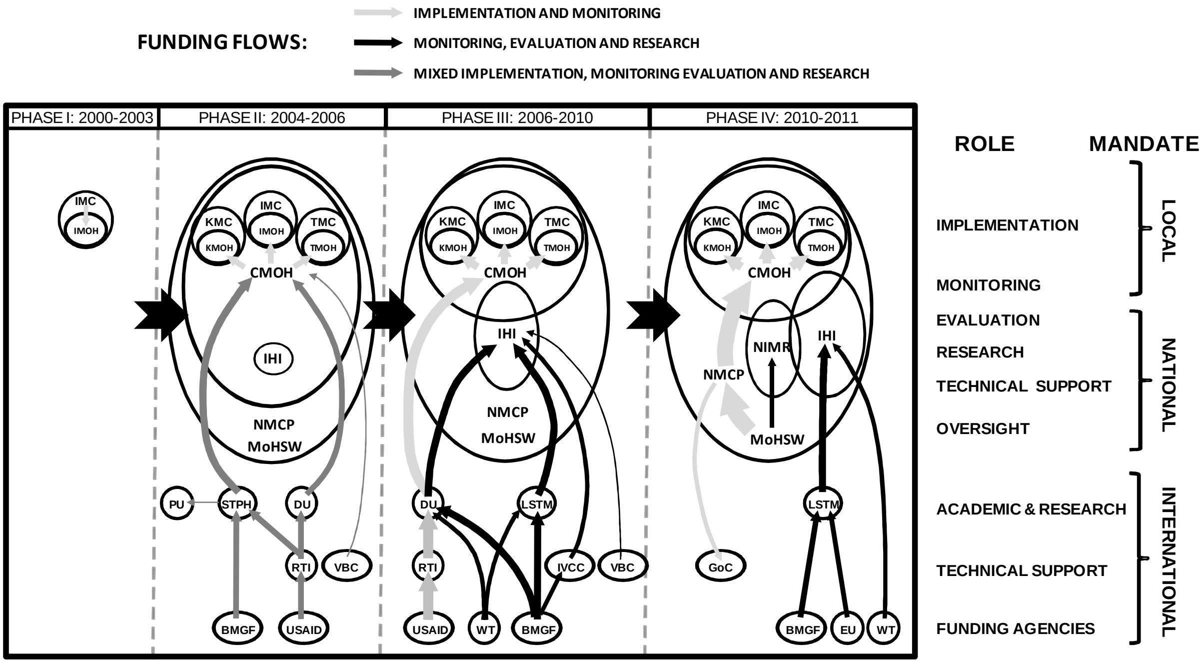

Figure 5.5.1 The origin, developmental and subsequent reforms of UMCP responsibilities among stakeholders over the six years (BMGF; Bill & Melinda Gates Foundation, CMOH; City Medical Office of Health, DU; Durham University, EU; European Union, GoC; Government of Cuba, IHI; Ifakara Health Institute, IMC; Ilala Municipal Council, IMOH; Ilala Medical Office of Health, IVCC; Innovative Vector Control Consortium, KMC; Kinondoni Municipal Council, KMOH; Kinondoni Medical Office of Health, LSTM; Liverpool School of Tropical Medicine, MoHSW; Ministry of Health and Social Welfare, NIMR; National Institute for Medical Research, NMCP; National Malaria Control Programme, PU; Princeton University, RTI; Research Triangle International, STPH; Swiss Tropical and Public Health Institute, TMC; Temeke Municipal Council, TMOH; Temeke Medical Office of Health, USAID; United States Agency for International Development, VBC; Valent Biosciences Corporation, WT; Wellcome Trust).

The UMCP has gone through a number of developmental stages and reforms (Figure 5.5.1) that have included changes in funding mechanism and management. This process has also been characterised by increasingly well-defined allocation of operational responsibilities for the larvicide application and associated monitoring, evaluation and research activities to distinct stakeholder institutions. The origins of the UMCP were seeded by one of the three Municipal Councils, namely Ilala, which implemented pilot community-based mosquito surveillance and control in 7 wards, starting at the turn of the century (Mukabana *et al.* 2006). It should be noted that during this first phase, larval source management for urban settings had yet to be re-integrated into the national malaria control priorities (MOH 2002) so this initiative was ahead of national malaria vector control policy at the time (Mukabana *et al.* 2006). The fact that this initiative was conceived by the council's own planning team and was supported by the local government health budget, in the absence of specific funding support from the national treasury or any external donor, particularly caught the attention of national and international research partners who shared the interests of local government stakeholders in Dar es Salaam in the potential of community-based larval source management for malaria control (Killeen 2003, Killeen *et al.* 2002a, Killeen *et al.* 2002b, Utzinger *et al.* 2001, Utzinger *et al.* 2002b). A joint stakeholders' meeting in Dar es Salaam in 2003 resulted in formulation of a joint plan for a modern, sustainable, community-based UMCP in Dar es Salaam (Mukabana *et al.* 2006). Actual implementation of the first surveillance activities began in March 2004 and the first 3 wards, with a population of over 128,000 residents, began to be treated routinely with larvicides in March 2006 (Fillinger *et al.* 2008). This early roll-out proved to effectively reduce malaria prevalence by over 70% (Geissbuhler *et al.* 2009) at a cost of <$1 per person protected per year, comparing very favourably with gold standard interventions such as LLINs and IRS (Worrall 2007). Between 2007 and 2009, these implementation systems were sequentially scaled up an area to cover 15 out the 73 wards of Dar es Salaam with over 614,000 residents. Furthermore, this pilot programme for larvicide application was complemented by targeted drainage interventions in some of the mosquito-infested, low-lying valleys at the heart of the city (Castro *et al.* 2009, Castro *et al.* 2010) that has been identified by the previous JICA-supported programme of the 1980s (Castro *et al.* 2004). With the help of national and international experts and funding from the Bill & Melinda Gates Foundation (BMGF) and the United States Agency for International Development (USAID), the UMCP was established (Figure 5.5.1) as a community-based larval source management programme focusing particularly upon routine application of microbial larvicides for malaria control in urban Dar es Salaam. The programme was integrated into the vertical management and coordination of the City Medical Office of Health (Fillinger *et al.* 2008, Mukabana *et al.* 2006). All the UMCP intervention and monitoring activities, such as participatory mapping, larvicide application and drain cleaning, as well as entomological monitoring of larval and adult stage mosquitoes, were implemented by community members engaged as Community-Owned Resource Persons (CORPs).

Although, the funding mechanisms and operational responsibilities were well outlined in the UMCP's guidelines, the overall distribution and organization of these among the various local stakeholders on the ground was rather chaotic in practice during this second phase of UMCP (Figure 5.5.1). Consequently, the program had to undergo significant reforms and growth in terms of redefining its operational responsibilities as well as the organization and management roles of its local stakeholder institutions (Figure 5.5.1). The most important reform was the increasing separation of responsibilities for the main players on the ground; the city and municipal councils focused more upon implementation of larvicide application and day to day larval-stage mosquito surveillance while the Ifakara Health Institute (IHI) was increasingly tasked with operational research, monitoring and evaluation that included surveys of adult mosquito densities and malaria prevalence among residents. Furthermore, these increasingly well-defined collaborative and administrative relationships enabled more defined and effective allocation of funds for both research and implementation purposes.

Throughout the second and third phases of the UMCP all relevant activities in Dar es Salaam relied upon channelling of donor funds through overseas institutions where most of the technical support partners were originally based. Initially money from the Bill& Melinda Gates Foundation (BMGF) and the United States Agency for International Development (USAID) channelled through the Swiss Tropical and Public Health Institute (STPH), and Research Triangle International (RTI), respectively, from where some of it was apportioned to additional technical support partners at Princteon University (PU) and Durham University (DU). At the start of the programme, this arrangement gave the overseas technical support partners a high level of administrative authority and they correspondingly played a significant managerial role on the ground in Tanzania where one of the experts (GFK) was seconded on a full time basis. Perhaps the most prominent characteristic of this phase is the distribution of personnel and funds for implementation, monitoring, evaluation and operational research through a single shared administrative system, team and programme office based at the Dar es Salaam city council. Perhaps the most challenging development stage for the UMCP and its various stakeholders was the subsequent division of responsibilities, personnel and funds so that complementary implementation and technical support capacities could be developed separately and synergistically at appropriate national institutions.

The third phase of UMCP was correspondingly characterized by much improved delineation of roles, responsibilities, funding and administrative systems of the national partner institutions. Phase 3 witnessed an increase in the number of donor partners with the majority of funding coming from BMGF and USAID and supplemented with research and training grants from the Wellcome Trust (WT) and Valent Biosciences Corporation (VBC), respectively. Essentially all implementation funds were channelled through RTI and then DU to support the implementation, monitoring and management activities of the city and municipal councils. A second administrative channel distributed funds through DU and, later on through the Liverpool School of Tropical Medicine (LSTM) to support the operational research, monitoring, evaluation and training activities of IHI in support of local government partners. At this stage the local government partners were mainly tasked with implementation and monitoring roles with money managed directly by the City Council whereas the national level stakeholders such as IHI and the National Malaria Control Programme (NMCP) of the Ministry of Health and Social Welfare (MoHSW) were responsible for providing overall oversight, technical support, monitoring and evaluation (Figure 5.5.1). As capacity of IHI in particular grew during this phase, these national supports, the role of overseas partners made a gradual transition from managerial to advisory and supportive. By the end of this third phase, the role of these external partners was largely restricted to technical advice, academic training and career support for the program. This marked a critical point in the evolution and growth of the UMCP into more than just a set of associated research projects program but rather as a functional programme with a strong collaborative national institutional base.

UMCP has recently entered a fourth phase during which it's governance structure and funding base has been improved further. The successes of the UMCP (Dongus *et al.* 2011b, Geissbuhler *et al.* 2009) captured the attention of the Tanzanian government which committed to finance all implementation activities of the UMCP. With this new thrust, UMCP has brought on board an important additional national technical support partners in the form of the National Institute for Medical Research (NIMR) and the role of the MoHSW has been greatly strengthened by channelling these funds through the NMCP which oversees all aspects of the programme. Complementary research, monitoring and evaluation activities are now separately funded through competitive international research grants from the European Union, BMGF and WT which are implemented by IHI so that technical expertise in the region has been strengthened and institutionalized. It is also critical to note that the institutionalization of most of the research and training capacity supporting the UMCP within IHI has enabled postgraduate training and career development for more than a dozen Tanzanian and Kenyan scientists and practitioners, registered at a diversity of academic partners in the region (University of Dar es Salaam, Sokoine University, University of Nairobi) and overseas (Swiss

Tropical and Public Health Institute, Durham University, Liverpool School of Tropical Medicine).

In contrast to the program sponsored by the Japanese government in the late 1980s, the current Urban Malaria Control Program (UMCP) delegates routine activities for both control and surveillance of mosquitoes to CORPs. While the CORPs have always been trained and paid by the City Council the sources of funding have varied over the years initially relying upon external donors but now directly supported by the national treasury. Overseen by ward supervisors and recruited predominantly through neighbourhood health committees, which proved to be more effective than through centralized management systems (Chaki *et al.* 2011, Chaki *et al.* 2009, Fillinger *et al.* 2008, Geissbuhler *et al.* 2009, Mukabana *et al.* 2006). The UMCP embeds an experimental evaluation of effectiveness, rather than efficacy into an operational program (Ostroff and Schmitt 1993), so that lessons may be learned that are scalable, generalizable and relevant for future policies and practice (Habicht *et al.* 1999). In the next section, we consider how scientific and administrative practices were aligned to transform Dar es Salaam into a site of bottom-up, grass-roots, community-based knowledge-production, participatory learning and effective (Geissbuhler *et al.* 2009) public health intervention.

5.6 The essential strategic role of community participants in larval source management

Because mosquito-breeding sites are less abundant and more easily located in urban areas, cities are regarded as the most suitable environments for larval control (Keiser *et* *al.* 2004, Robert *et al.* 2003). But, as we know from Orenstein Gorgas, Watson and Soper, effective larval surveillance and monitoring requires comprehensive knowledge of the urban landscape at remarkably fine spatial scales (Orenstein 1914, Shousha 1948, Soper and Wilson 1943, Watson 1953). In this regard, Dar es Salaam poses considerable challenges which are common to many African cities, suggesting that lessons learned may be more broadly useful beyond this specific context. Like essentially all African cities, Dar es Salaam is undergoing rapid growth, the vast majority of which is unplanned (Amer 2007). Propelled by population increase, deficits in basic infrastructure, and marked by the significance presence of 'rurban' economic activities such as urban farming (Dongus 2001, Dongus *et al.* 2009, Kiunsi 2009), Dar es Salaam's ongoing sprawl encompasses a diverse range of possible *Anopheles* habitats, from blocked drains and ditches, to cattle troughs and garden furrows, to tire tracks and pit latrines to irrigated fields and even rice paddies (Chaki *et al.* 2009, Dongus *et al.* 2009, Sattler *et al.* 2005, Vanek *et al.* 2006). In the urban context, these habitats are highly dynamic and prone to change because of the high level of human activity, notably agriculture and construction (Dongus *et al*. 2009, Killeen *et al*. 2002b, Killeen *et al*. 2006c). Also, mosquitoes in cities continually and rapidly adapt to the peculiar selective pressures of urban environments so that their behaviours and reproductive ecology may differ from their better-studied rural counterparts (Keiser *et al.* 2004, Robert *et al.* 2003) (Coluzzi *et al.* 1979, Gramiccia 1956). For instance, while it was initially assumed that most *Anopheles* only breed in clean and clear water (Gillies and DeMeillon 1968), in Dar es Salaam they are now found in habitats polluted by rotting vegetables or human waste including drains and swamps (Sattler *et al.* 2005) and similar observations have been reported from other African cities

(Chinery 1984). These biological and environmental characteristics of cities make larval habitat distribution even more difficult to predict in cities, re-enforcing the commonly-held view that participatory learning through regular surveillance by community members (van den Berg and Knols 2006) will be required for larval source management to react and adapt to highly dynamic and often surprising patterns of mosquito proliferation (Killeen *et al.* 2006c, Mukabana *et al.* 2006, Townson *et al.* 2005). Furthermore, the nature of human societies in cities also create very specific and significant challenges that further emphasize the need for larval source management programmes to achieve effective community engagement and mobilization (Bang and Shah 1988). Urban populations are typically far more diverse, dynamic and unstable with higher rates of turnover, migration and crime. This in turn creates concerns about security and privacy so walled or fenced plots can be difficult to access (Chaki *et al.* 2011). In the context of Dar es Salaam, access to the myriad of individual plots that comprise most of the city has already been clear identified one the greatest challenges to effective surveillance, and presumably control, of larval-stage mosquitoes (Chaki *et al.* 2011, Chaki *et al.* 2009, Vanek *et al.* 2006).

Advances in Remotely Sensed (RS) imagery, Global Geographical Information Systems (GIS) and Global Positioning Systems (GPS) provide tools to render these dynamic micro-ecologies visible and can even incorporate models that relate malaria transmission to mosquito dispersal (Killeen *et al.* 2003, Service M.W. 1997, Thomas and Lindsay 2000). However, cartographic problems extend beyond those posed by physical geography. The most recent official map of Dar es Salaam dates from 1995, so at the outset of this study, the administrative boundaries of new settlements or the emerging patterns of land ownership were, to a large extent, unknown or vaguely defined. Recruiting participants through street-level committees was, therefore, of critical importance because only their familiarity with geography and residents of their neighbourhoods could enable location of and access to mosquito-breeding sites, many of which are located within private homes and gardens (Chaki *et al.* 2009).

5.7 Community engagement and mobilization tactics

With the goal of linking lived understandings of the city with the images produced by GPS technology, the UMCP developed a novel protocol for "participatory mapping" (Dongus *et al.* 2011a, Dongus *et al.* 2007). The process began with sketch maps drawn by individual CORPs – often with the help of household and plot owners – of the Ten Cell Unit area for which he or she was responsible. The CORPs identified and delineated each plot in relation to small-scale geographic features visible on the ground such as roads, drains, walls or houses and corresponded to the existing administrative boundaries (Dongus *et al.* 2011a, Dongus *et al.* 2007). The sketch maps were envisaged to enable the CORP to assign a unique number to any larval habitat found within a plot and guide their orientation in the field, as well as help the supervisory staff to identify the habitats unambiguously when inspecting the work of that CORP.

The involvement of specialist, non-community-based personnel from the centralized institutions described in figure 5.5.1, only begins when a geographic technician or scientist from one of the technical support partners accompanied the CORP to his or her area to verify, correct and formalize these intuitive sketch maps. Walking along all the boundaries of TCUs, neighborhoods and wards, the technician and formally mapped the boundaries to an aerial photograph by features on the ground of that part of Dar es Salaam. This ensured all the existing TCUs within a ward and any previously un-surveyed areas, which constituted >30% of the total area in pilot evaluations, were identified and included into the sketch maps (Dongus *et al.* 2007).

Of course, knowing where to search or treat was only part of the problem. Ultimately, this carefully mapped array of plots simply provides a geographic and administrative framework within which the tasks of larval control and surveillance can be assigned, monitored and managed (Dongus *et al.* 2007, Fillinger *et al.* 2008, Geissbuhler *et al.* 2009). Specifically, in the original implementation system described in detail elsewhere (Fillinger *et al.* 2008), every plot was to be visited weekly by one member of each of two distinct teams-first a CORP responsible for rigorous application of larvicide and then, within one or two days, a CORP responsible for surveying potential mosquito larval habitats and whether they contain aquatic-stage mosquitoes (Chaki *et al.* 2011, Chaki *et al.* 2009, Fillinger *et al.* 2008).

As the vignette in the sections below illustrates, some plots are more closely guarded than others. Watchdogs, gates and hostile owners are sometimes enough to dissuade CORPs from approaching a property, let alone asking permission to enter, search for and treat any potential breeding habitats it may contain. Echoing Ronald Ross's recommendations in

Mosquito Brigades, the UMCP guidelines for the CORPs situate larval control within local norms and relations:

> *For the purposes of our programme, a plot is defined as a specific physical area with an identifiable owner, occupant, or user…Knowledge of who owns, occupies or uses a certain plot is very important if you are to gain unlimited and regular access in future as this is the person who has the power to say yes or no!* (Fillinger *et al.* 2008).

The need for communal consenting to the success of community-based larval targeted interventions is emphasized by the following reaction from one resident:

> *Who are you? Why are you entering my compound? You should have knocked first and wait for the gates to be opened". (Resident of UMCP intervention ward, Dar es Salaam, 2009).*

This relationship was clearly illustrated when a member of the scientific team, who was conducting a surprise evaluative visit, accompanied one of the CORPs as he monitored four of the thirty sites for which he is responsible each week. They walked for a half an hour to the first site, consisting mostly of unplanned settlements, a network of dust roads, river-banks and garden plots. Here the CORP was greeted by a few of the residents, who let them into their plots to search for any standing water. However, as they reached one of the fenced compounds, the CORP and the accompanying scientist pushed open the gate and made their way inside, only to find a man holding a knife, who told them – in no uncertain terms – to get out.

In other words, the fundamental geographic and administrative unit of larval control and surveillance is the plot, embedded in social systems of regulation, and sometimes and informal land markets, often beyond the purview of public authorities (Kombe and Kreibich 2001).[7] But while the plot provides the *de-facto* site of intervention, the city – or at least a representative portion of it – is the geographic unit of programmatic management and overall evaluation. This shift in scale is not only a matter of covering more ground; rather it requires integrating the plot into large-scale systems of urban governance. In warning against the pitfalls of community participation in vector control Service, emphasized that "the expected outcomes of collaborative control efforts by the community need to be explicitly explained to the people" (Service 1993a). Moving from pilot plots to urban infrastructures not only introduces new actors, but also different sources of concern relating to how they interact with each other.

5.8 Scaling responsibilities: the complementary roles of communities and institutes

This process of bringing such individual small plots into the state view and support systems involved an iterative network of reportage: summaries, charts, spread sheets and

[7] Kombe and Kreibich demonstrate how land-ownership, rights and use are regulated on the level of the neighborhood with the support of *Mtaa* leaders and organised community groups in authenticating and registering land rights, and while they deploy norms and procedures closely linked with the formal sector, they do not have statutory powers or legal mandate to do so.

reports connecting CORPs, Ward Supervisors, Municipal Inspectors, Municipal Coordinators and the City Council on a daily, weekly and monthly basis (Fillinger *et al.* 2008). This system of annotated exchange enables the assessment of performance and evidence-based management at all the necessary spatial and temporal scales (Figure 5.5.2), detailing the roles of individuals and communities with those of their institutional partners (Fillinger *et al.* 2008). Critically it allows those different administrative levels, from TCUs all the way up to the national Ministry of Health & Social Welfare, to interact synergistically with each other while operating on corresponding fine or broad spatial and temporal scales. Critical to this strategy is the view that while effective management of mosquito populations begins on very fine scales with decentralized, community-based local management, the ultimate goal of achieving effectiveness at scale requires central management systems, funding, oversight and institutional support. The role of the institutional partners is to coalesce a myriad of otherwise independent grass roots, community-based management units into a single, stable coherent programme with consistent, evidence-based targets and monitoring systems, high-level governance stakeholders and expert scientific support.

Of course, in practice, some degree of discord and friction between the various levels and partners with each other and with the pre-existing urban institutional fabric are inevitable and perhaps even healthy and instructive. In Tanzania, popular participation has played a central role in colonial and postcolonial development schemes (Pratt 1976, Samoff 1979). On the one hand, the familiarity of the idiom has given contemporary participatory approaches a peculiar traction. However, as the CORPs' experience suggests, translation between disparate communities and the central institutions that support, service and mobilize them can result in a considerable amount of friction at their interface (Chaki *et al.* 2011, Chaki *et al.* 2009, Dongus *et al.* 2010). Understanding the diverse models and histories of participation is therefore particularly relevant in the context of larval control, as the space of intervention straddles the public, private, official and informal configurations of urban life.

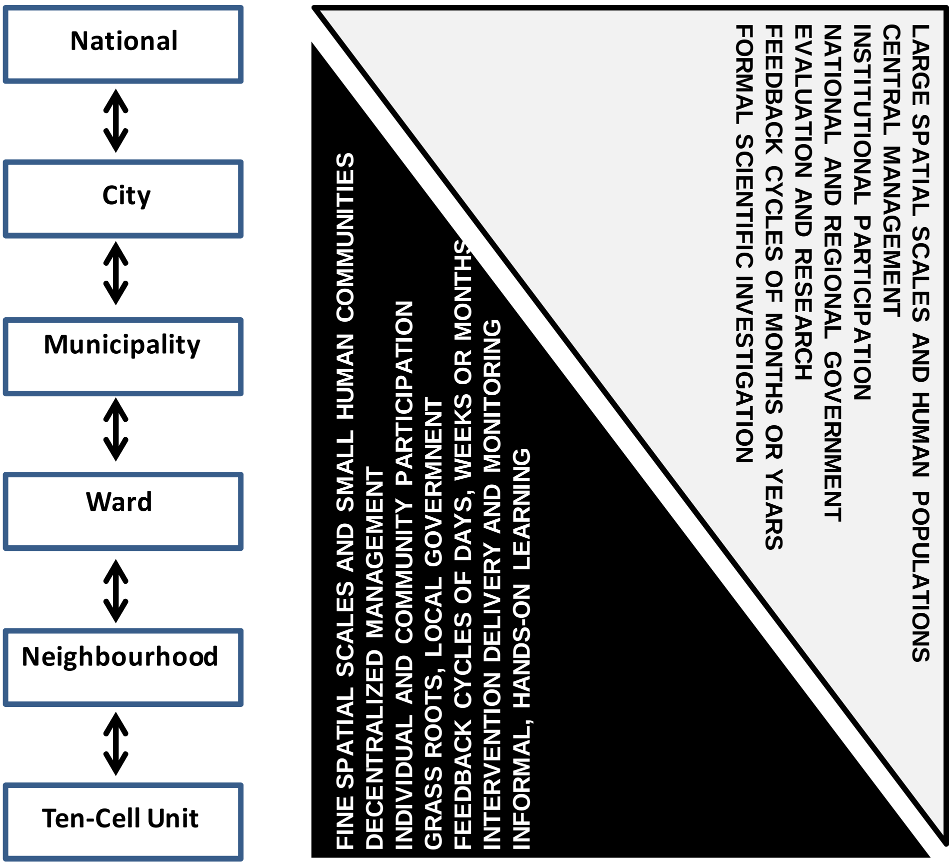

Figure 5.5.2: The scaling up and subsequent distribution of UMCP responsibilities among different stakeholders at the various administrative levels as well as spatial and temporal scales.

5.9 The community-local government interface

The grass roots workers, namely CORPs, Mtaa leaders and most ward supervisors that comprise the vast majority of the programme's personnel and implement most of the work on the ground, all work on a voluntary, very modestly-remunerated basis. In contrast to this, the municipal and city council officers that manage these teams are salaried government employees while the research partners enjoy even better employment conditions but assume no direct responsibility for the delivery of effective malaria control. Obviously, these disparities are most clearly felt by the CORPs responsible for the labour-intensive, day-to-day execution of the programme activities. Though they receive some compensation for their efforts, the value of these stipends is far less than the salary received by personnel formally employed by participating institutions. Moreover, payment through the established legal system for municipal mobilization of casual labour is hinged upon the completion of daily tasks, with no long-term security or provision for illness, bereavement or leave of any description. Though volunteering on what is legally considered a casual basis, the time and sheer physical stamina it takes to locate and treat each and every potential breeding habitat across large areas means that the CORPs have limited opportunity to do any other work (Chaki *et al.* 2011). For most, participating in the UMCP was their primary, if not sole, source of income (Chaki *et al.* 2011). Compounding the difficulty of negotiating access to private residences, the demands placed on them by the UMCP were perceived by the CORPs as unrealistic and unfair (Chaki *et al.* 2011).

Interestingly, despite their meagre remuneration, grass-roots personnel recruited as CORPs often performed routine activities on the ground better than salaried local government officers (Authors' personal observations), and those recruited through local community leaders significantly outperformed those recruited through central management staff (Chaki *et al.* 2011), so over the course of the programme, ward supervisor positions were increasingly filled by promoting the former (with a modest pay increase) rather than assigning the latter. Ultimately, the success of the programme depends on the capabilities and motivation of the CORPs to negotiate access to plots and to locate and treat larval habitats. Despite efforts to decouple project evaluation from disciplinary action against CORPs, the integrity of the experiment (e.g. its value as a demonstration of the impact of larval control on malaria transmission) and the success of the programme (a reduction in the incidence of malaria) rested on the capabilities of the CORPs to negotiate access to plots and to locate and treat larval habitats. The composition of the CORPs and the form of their recruitment may have to be re-evaluated: While, on the whole, CORPS are more successful at locating breeding habitats when they are engaged by local leaders than when the program's staff, there may well be good reasons to hire fewer but better paid CORPs (Chaki *et al.* 2011).

5.10 The researcher-implementer interface

The interface between local government implementers and their technical support partners also represents specific challenges which are critically important to overcome. First of all, the level of involvement of scientific staff in training, monitoring and management activities as technical advisors determines the fundamental nature of the evidence derived from impact evaluations and these issues must be carefully managed throughout the development of such programme. Where the level of such direct technical support is high, estimates of impact tend to reflect probabilistic evidence of efficacy under conditions which are less-representative of those of sustainable scale up than would otherwise be the case (Habicht *et al.* 1999). However, where such pilots are intended to form the nucleus of sustained public health programmes and produce evidence of effectiveness under representative conditions of routine implementation conditions, it is important to minimize such direct technical support and more clearly delineate the distinct and complementary roles of implementation and scientific partners (Habicht *et al.* 1999). The contemporary UMCP described here was initially established with research-based funding and a single programme office at which local government officials and scientists seconded from overseas worked together under one roof with poorly differentiated or defined roles (Figure 5.5.1). As the programme matured, a team of early-career Tanzanian scientists was established at a national research institute (IHI) operating from a separate office and the role of the expert partners from overseas shifted to providing a mixture of technical and academic support to national implementers and scientists with far more clearly defined and distinguished roles and responsibilities (Figure 5.5.1 and figure 5.5.2).

Of course the differentiation of such roles and responsibilities inevitable creates distinctions and interfaces which present specific challenges to maintaining effective collaboration. Specifically, it must be recognized that it is extremely difficult for implementation partners to be entirely objective when assessing their own performance, as can be seen when one compares independent surveys of larval surveillance coverage and sensitivity (Chaki *et al.* 2011) with internal monitoring data of the UMCP management system (Fillinger *et al.* 2008). However, it is unreasonable to expect anyone to completely defy the natural pressures that arise from self-assessment so this is where the real value of independent scientific partners lies: to objectively and openly shed light on disappointing or frustrating features of implementation (Chaki *et al.* 2011, Chaki *et al.* 2009, Vanek *et al.* 2006) while also lending credibility to encouraging evidence of success (Dongus *et al.* 2011b, Geissbuhler *et al.* 2009) through unbiased data collection, analysis and interpretation. Our experience has been that maintaining these relationships is as strategically and vitally important as it is challenging so a lucid understanding of how these complementary roles are aligned, and a commitment to sustain them, is essential to cultivate on both sides of this interface and among high level oversight partners.

5.11 Progress and Prospects

Despite these collaborative challenges, not to mention the frequent operational setbacks that are all a normal part of translating theory and good will into *de facto* public health practice, malaria prevalence and mosquito densities have consistently declined across the UMCP pilot area as larviciding has been sequentially scaled up (Dongus *et al.* 2011b). Opportunities clearly exist for substantial improvement of many of the surveillance and intervention systems that comprise the UMCP or which remain conspicuous by their absence. For example, the community-based larval surveillance systems that have been evaluated thus far are clearly insufficient (Chaki *et al.* 2011, Chaki *et al.* 2009) and the overhauled forms of this monitoring mechanism that have been instituted since 2009 remain to be characterized. While effective systems for safe, cost-effective community-based monitoring of adult vector populations on fine temporal and spatial scales have been developed and evaluated (Chaki *et al.*, Unpublished), the same cannot yet be said for malaria incidence burden. While considerable systems innovation, optimization and evaluation remains to be executed, the results of the earliest formal evaluation (Geissbuhler *et al.* 2009) were encouraging enough for the government through the Ministry of Health and Social Welfare (MoHSW) to decide to take over funding and management of the programme. The national government's enthusiasm is shared by the Dar es Salaam City Council, which has expressed its commitment to expand the UMCP, from the fifteen wards where it was initially conducted, to all the urban and peri-urban areas of the city, then 73 wards of the by 2013.

In this paper, we have drawn together historical and empirical resources to illuminate how a city is inter-articulated by governance mechanisms, policy reforms and institutional relations, as well as scientific evaluation and research practices. Specifically, we have explored the relationship between the objects of public health interventions and the institutional landscapes in which they are located, with the hope of forging strong collaborative models that engage and mobilize communities through local and national institutions to achieve maximum impact and sustainability. To conclude, here we summarize the implications of this argument for participation in and responsibility for larval control and public health governance more broadly.

The integration of the traditionally vertically-managed vector control activities into a decentralized community-based implementation system has achieved encouraging early success (Dongus *et al.* 2011b, Geissbuhler *et al.* 2009) and led to increased resources for wide-scale implementation of larval control in urban Dar es Salaam. The clear hierarchical structure associated with vertical organization of this community based and management systems, as well as the clear distinction in the lines of responsibilities across the various scales within UMCP, contributed to the evolution and subsequent growth of UMCP (Figure 5.5.2). Although the UMCP started off rather chaotically with the roles of the various partners ambiguously assigned (Figure 5.5.1), the central coordination role of the city council has enabled institutionalization of strengthened management and planning, improved community-mobilization capability, and capacity to exploit national and international funding systems. Often, health sector decentralization has been associated with a dramatic reduction in the number of health experts generally, and specifically entomologistists, hence weakening internal capacity for monitoring of control operations at the various levels of central or local government (Buchan 2000, Dovlo 2004, Kritski and Ruffino-Netto 2000, Zimmerman 1992). Within the current UMCP, the reverse has been the case because strong collaborations between the local government and research partners has allowed stable career development and growth of distinct professional cadres at these complementary and very different institutional bases. This parternership has witnessed six researchers undertake PhD studies and five government employees graduating with MSc degrees in parasitology and vector ecology.

The UMCP presents a fascinating case of how malaria becomes a ‘matter of concern’ and the complex relationships between such a concern, scientific practices, technical instruments, and the role of government and other institutions. Our study highlights the ways in which the material and institutional environment intervene in the creation of public spaces, and trigger new occasions for participation. In Dar es Salaam, community-level malaria control is entangled in a complex ecology of larvae dippers, blocked drains, tin cans, fences and gates, sketch maps, plots which are now embedded in well-defined political and institutional infrastructures. Ultimately, the high degree of program ownership by the city council and three municipalities, coupled with catalytic donor funding and technical support from expert overseas partners have enabled establishment of a sustainable internally-funded program implemented by the national MOHSW.

CHAPTER SIX

SUMMARY AND GENERAL DISCUSSION, CONCLUSION AND RECOMMENDATIONS

This chapter was written by

Prosper Chaki[*], and edited by Gerry Killeen,

Preamble:

Indoor residual spraying (IRS) of houses with insecticides (Kouznetsov 1977, Pluess *et al.* 2010) and insecticide-treated nets (ITNs) (Lengeler 2004) are the front line malaria vector control measures recommended across the globe and in Africa particularly (WHO 2010). However, increased outdoor feeding behaviour (Braimah *et al.* 2005, Bugoro *et al.* 2011, Govella *et al.* 2010b, Oyewole and Awolola 2006, Pates and Curtis 2005, Russell *et al.* 2011a) and resistance to insecticides (Kelly-Hope *et al.* 2008, Ranson *et al.* 2010) among residual vector populations define limits to what even these proven priority measures can achieve (Eckhoff 2011, Govella *et al.* 2010b, Griffin *et al.* 2010, Killeen *et al.* 2011). There has therefore recently been a revival of interest in implementing and evaluating traditional larval source management (LSM) strategies to complement ITNs and IRS (Fillinger and Lindsay 2011, Fillinger *et al.* 2009, Killeen *et al.* 2003, Killeen *et al.* 2002b, WHO 2004, WHO 2006a). Some successful recent efficacy trials in rural Kenya (Fillinger and Lindsay 2006, Fillinger *et al.* 2009) and Eritrea (Shililu *et al.* 2007) have now been complemented by encouraging evidence of effectiveness in the context of the Dar es Salaam Urban Malaria Control Programme in Tanzania (Dongus *et al.* 2011b, Geissbuhler *et al.* 2009).

Rapid urbanization will soon place half the population of Africa in towns and cities by 2030, where high human population density and comparatively conducive infrastructural and governance conditions render LSM a more immediately feasible option for sustainable development than in rural contexts (Hay *et al.* 2005, Keiser *et al.* 2004, Robert *et al.* 2003). LSM has a long history of success in urban Africa, dating back almost 100 years (Castro *et al.* 2004, Clyde 1967). Before World War II and the advent of modern adulticides for IRS and ITNs, combinations of environmental management, larviciding, mosquito-proofing houses, personal protection measures, and antimalarial drugs were successfully applied to malaria control (Keiser *et al.* 2005, Lindsay *et al.* 2002, Utzinger *et al.* 2002b). Urban malaria control in Tanzania during the 1960s relied heavily upon larviciding and community-implemented environmental management, such as drainage and habitat filling, resulting in malaria transmission that was considered to be of limited magnitude (Clyde 1961a).

Community-based service delivery is considered be vital to the effectiveness, affordability and sustainability of vector control generally (Heintze *et al.* 2007, WHO 1983, Winch *et al.* 1992) and particularly to the labour-intensive LSM programmes in particular (Killeen *et al.* 2006c, Mukabana *et al.* 2006, Townson *et al.* 2005, WHO 2004). The highly-localized task of detection and management of mosquito larval habitats crosses public and private landscapes at all spatial and governance scales so there is a clear need to better understand the practices of governance that LSM necessitates and the collaborative potential that exists between malaria-afflicted communities, research institutions and all levels of local and national government (Killeen *et al.* 2006c, Mukabana *et al.* 2006). While in this case community participation can be viewed as a human right of citizens, it is also a strategy to deepen accountability of participating institutions to the health and addressing the needs of the serviced community. Participatory planning is essential to enhance local capacities and ensure community ownership, without which interventions usually fail because services remain underutilized or misused (Hongoro and McPake 2004, WHO 2006b). However, the scope and extent of community participation usually remains poorly defined (Rifkin *et al.* 1988) and many have criticized utopian assumptions about the capacity of the 'community' to provide a panacea for a number of entrenched economic, social and health problems (Bhattacharyya 1995, Leach *et al.* 2005). This research therefore examined the origins and evolution of a city-level LSM programme over the last eight years in urban Dar es Salaam, Tanzania to better understand how such operational research projects contributes to public health governance and establishment of sustainable service delivery programmes. A general call to all the policy makers, international agencies and donors to recognize the economic value of such a positively reinforcing effort against mosquitoes, based on larval source management. Further to the work presented in the previous chapters, a series of sections summarizing how each objective has been addressed, the implications of the results, and remaining knowledge gaps are discussed as follows.

Summary and indepth review of the major outcomes of the research

6.1 Synopsis of the main findings implications for monitoring and evaluation of malaria control programmes

The findings of this study emphasize the need for integrated and highly institutionalized LSM for controlling malaria, as well as the need for rigorous independent evaluation systems to track progress towards set targets. This thesis has been divided into six chapters, with chapter one giving the general state of the art with regards to malaria control and the background to the research questions that are later addressed in chapters

2, 3, 4 and 5. As illustrated in figure 6.1, this current chapter summarizes the five research chapters and what was done to address the four objectives.

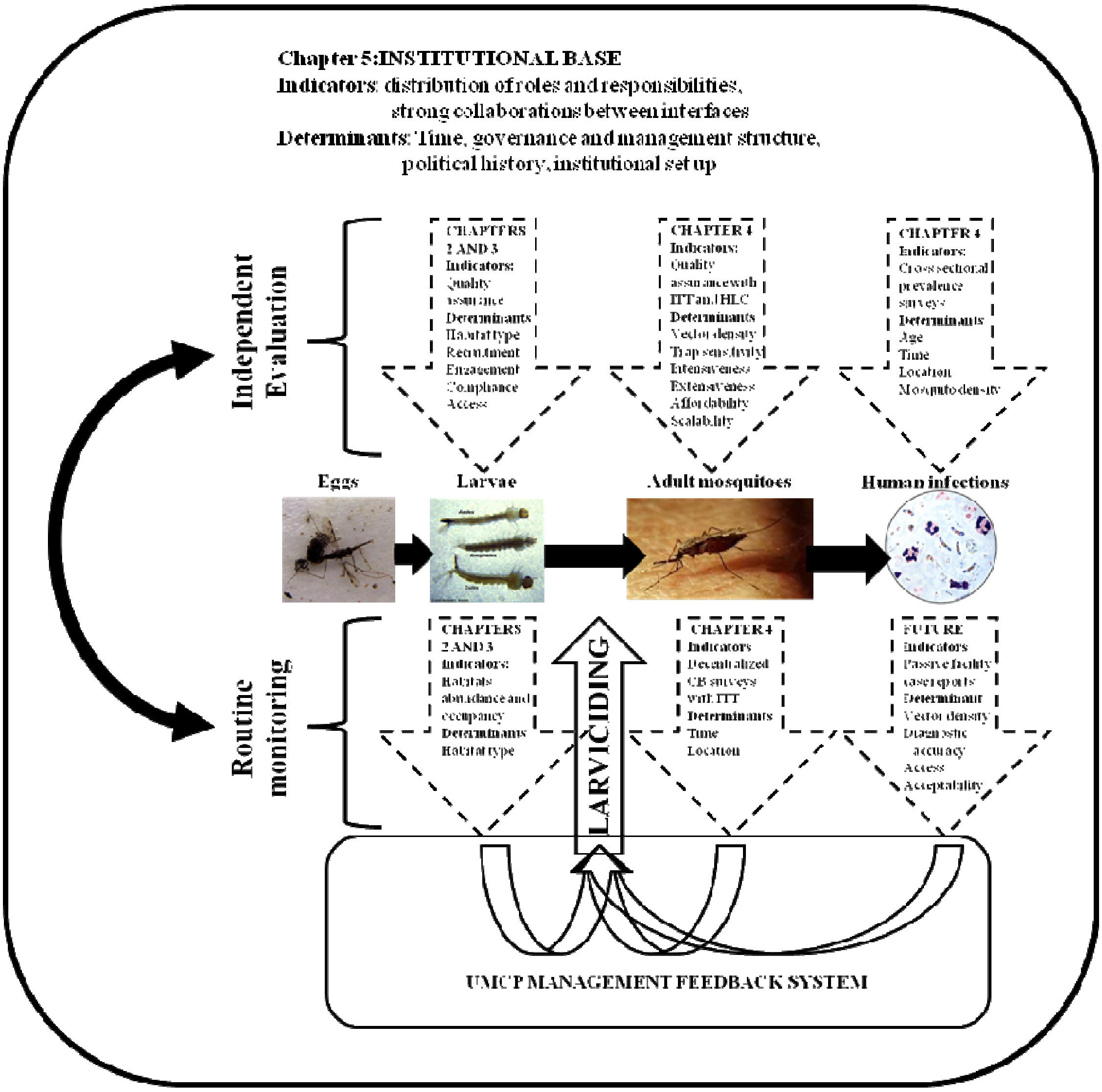

Figure 6.1.1: Schematic presentation of the different chapters and sections, various indicators and determinants studied in this thesis with regard to the vector and malaria disease life cycle.

In chapter 2, a mixed method, cross-sectional survey approach was adopted to evaluate the effectiveness of operational, community-based larval habitat surveillance systems within the Urban Malaria Control Programme (UMCP) in urban Dar es Salaam, Tanzania. This was implemented through closely assessing the ability of CORPs to detect and report mosquito breeding sites and larvae. An in-depth look at the environmental and programmatic determinants of surveillance coverage and sensitivity in this urban environment was undertaken to identify strengths, weaknesses and opportunities for improvement. Detection coverage was estimated as the proportion of wet habitats found by the investigator which had been reported by CORP whereas, detection sensitivity was estimated as the proportion of wet habitats found by the CORPS which the investigator found to contain *Anopheles* larvae that were also reported to be occupied by the CORP. The findings in this chapter led to the conclusion that accessing habitats presents a major challenge to larviciding personnel in this city, and probably in most urban settings, because of two major reasons. First, the vast majority of compounds are fenced for security reasons. Secondly, lack of familiarity among the recruited volunteers was common and strongly influenced their performance. This led to the recommendation that the then existing UMCP system for larval surveillance in cities be revised by introducing rigorous external quality control of the internal process indicators and more community engagement to improve access to enclosed compounds and the sensitivity with which habitats are searched for larvae.

Later on in chapter 3, mixed method, cross-sectional survey was applied to investigate CORPs' demographic characteristics, their reasons for participating in the UMCP, as well as their overall work performance. Here it was revealed that major variations exist in individuals' perceptions of the meaning of participation. While the program managers thought of it as being voluntary, the CORPs themselves perceived their role as being more professional rather than voluntary, with participation being a *de facto* form of employment. The study also demonstrated discrepancies in the performance of larval surveillance CORPs associated with their channel of recruitment into the program and whether or not they were working within their home communities. It was clear from these findings that there are major deficits with regard to staffing such community-based public health programs. Apart from improved communication strategies, one clear recommendation from this chapter is the need for improved employment conditions as well as involvement of the local leaders and respective committees in identifying, recruiting and maintaining individual program staff. At the program level, a simpler, more direct, less extensive community-based surveillance system in the hands of a few, less burdened, better paid and maintained program personnel was recommended to improve performance and data quality. The streamlined larval surveillance system involved adopting a much less extensive but better controlled community-based surveillance with fewer supervisors who were better paid, motivated and retained carrying out the activity. The Ward supervisors were obliged to visit a total of 12 TCUs a week, 6 of which randomly chosen by the program manager and left to chose the remaining 6 at their own discretion. A sub sample of these was picked and given to the quality control managers from respective municipality for counteracting the quality of supervisors' information. The daily summary reports from these surveys were then uploaded using mobile phones with in-built standardized forms onto a web-based server and made available to program managers through a password protected link.

Chapter 4 evaluates the epidemiological predictive power and cost-effectiveness of an intensive and extensive community-based adult mosquitoes monitoring system to support management of the UMCP larviciding work. This evaluation included a comparison between the decentralized community-based surveys (CB) using Ifakara Tent Trap (ITT-C) versus centralized quality assurance (QA) surveys using either ITT-C or human landing catches (HLC), as well as a cross-sectional survey of malaria parasite prevalence in the same housing compounds. The results of this work revealed that decentralized, community-based use of the ITT-C was the most cost-effective and epidemiologically relevant way to monitor adult malaria vector mosquitoes. Although this approach had low relative sensitivity per night of sampling, it allowed far more intensive, extensive longitudinal surveillance.

Motivated by encouraging impact of this community-based larviciding initiative (Fillinger *et al.* 2008, Geissbuhler *et al.* 2009) and the successful development of new systems for routine surveillance of adult mosquitoes, chapter 5 assesses the evolving roles and responsibilities of communities and institutions in the UMCP. The UMCP developed a clear hierarchical structure nested within the vertical management system of this primarily community-based programme, with clearly defined lines of responsibilities across the various relevant scales. This chapter examined how public health governance is pronounced through scientific protocols, development practice and the specific political history of Tanzania. Our focus was on understanding the encounter between CORPs, programme managers, scientists and residents as well as the forms of responsibility that emerge when research practices are embedded into the fabric of urban settings. Overall, the work presented here explores how best to achieve effective implementation of larval surveillance and control under operational programmatic conditions by closely evaluating the managerial and monitoring processes involved (Figure 6.1).

6.2 Community-based monitoring of mosquito larvae as a management tool for measuring coverage of larviciding

While various studies have addressed the question of efficacy of larvicide application for malaria vector control, only a few have raised the question of how much coverage with larviciding is truly required achieving worthwhile impact. The UMCP in Dar es Salaam, the place where this work was based has adopted the working hypothesis that comprehensive coverage will be essential if larval control is to achieve substantial reductions of malaria transmission and disease burden. These high coverage targets are based on the assumption that even if reliable targeting criteria could be identified, the successful application of such technically complex criteria by community personnel is likely to be unreliable, impractical and unaffordable (Killeen *et al.* 2006c). The impact of any larval source management program will probably be compromised unless almost all aquatic habitats are identified and treated or eliminated. We further explore the participatory approaches and the governance practices of the UMCP, outlining the challenges and opportunities of grassroots participation within the program. In particular we are concerned with how responsibility for the UMCP was shaped by the technical and operational demands of larval control, on one hand, and the political history of Dar es Salaam, on the other.

The results in chapter 2 emphasize the importance of detection and subsequent reporting of potential breeding habitats, and the late-stage *Anopheles* larvae therein, as programmatic indicators of larval control implementation gaps because it represents the most practical scalable indicator for imminent emergence of adult malaria vectors. However, the usefulness of this information to the UMCP is dependent on the *sensitivity* and *coverage* of the surveillance system. However, the experience with CORPs in Dar es Salaam demonstrated that neither of these requirements was achieved with simple community engagement strategies (chapter 2) despite the extensive training activities of the UMCP to impart the right technical skills to the CORPs (Fillinger *et al.* 2008). Sensitivity was particularly poor and the fact that surveillance teams in the larviciding areas detected proportionately fewer habitats with *Anopheles* larvae than those in non-larviciding areas, even when they had previously reported the habitats. While immediate explanations to this would be attributed to lower larval density in treated habitats, reduced thoroughness among individual CORPs when searching habitats as they assumed sites have been treated could also have caused that. Either way, this points to biases in the perspectives or supervision practices of the ward supervisors with the competing interest of being responsible for larvicide application and surveillance. These findings in chapter 2 present some intriguing lessons and fundamental questions that need to be addressed if

LSM through community engagement strategies are to have a sustainable future in Tanzania and elsewhere in Africa. So the question here should be how to best plan these programs so that implementing and monitoring functions are distinct and quality assured, yet integral, of the program. The fact that larval occupancy in areas with larviciding was only reduced if habitats had been found by surveillance CORPs (Table 2.3.6, chapter 2) strongly emphasizes the need for carefully incorporating such independent quality assurance surveys as process indicators for larval control programmes. These results also suggest that if surveillance CORPs did not enter a plot or detect the habitat, larviciding CORPs were also less likely to enter and treat them. These findings call for special emphasis process upon directed monitoring strategies that more compliant operational teams and engagement of the community in holding these teams accountable for service delivery, as well as to allow area-wide access to plots and compounds.

In general residents with fenced gardens should be made aware by the program that they frequently contain malaria vector larvae,and motivated to support control activities. They should be made aware of the options they have to address their own mosquito problem, by either implementing feasible small-scale environemental modification options or by allowing and supporting UMCP CORPs to access their compounds. Again the key question here is how will the programs best achieve this in practice on a sustainable basis. Chapters 2, 3 and 4 all emphasize the crucial roles that the CORPs and the resident local leaders can play in sensitizing and mobilizing the community and enhance program performance.

Although a previous study (Dongus *et al.* 2010) of UMCP reported tremendous improvement by the CORP surveys largely due to the training that UMCP offered this study was entirely subjective and lacked testable process indicator outcomes. Chapter 2 suggests there is an urgent need to dramatically improve coverage and especially sensitivity, of these community-based monitoring platforms. Despite adopting a very labour-intensive and expensive comprehensive larval surveillance system (Fillinger *et al.* 2008), survey quality and coverage were ubiquitously inadequate system. These findings imply that some important shortcomings exist in the planning and design of these surveillance systems, which the UMCP and similar future programs should take into consideration. Critically exploring possible reasons for the failure by UMCP teams of surveillance CORPs to detect and report the majority of the habitats, including most of those containing larvae, CORPs' unfamiliarity and, most importantly, to the presence of fences stood out as being the most influential factors. The, take home message for mosquito control programs focusing on larviciding in urban areas is that it is essential to have full, regular access to all open spaces potential for accommodating aquatic habitats where mosquito proliferation takes place. This should include all fenced plots and other areas with restricted access for the public, and thus requires substantive and open collaboration between stakeholders. Such collaboration could be achieved by enhancing access to knowledge and information among the various stakeholders at all levels. The observations in chapter 3 emphasize that grassroots participation should go beyond involving the communities in implementing the interventions but rather even in identifying the right people in their societies that would best fit the specific tasks. Again the question here is who should be responsible for the recruitment process? Should it be the scientific and/management staff member of the program or the local leaders of the recipient communities? The findings in chapter 3 partly respond to this question by illustrating how the latter are generally better suited to the job: habitat detection coverage was higher among CORPs recruited by the local government leadership and the detection sensitivity was generally lower among CORPs residing in areas away from their areas of responsibility. Furthermore, to advance this argument I recommend that the recruitment process of the community personnel needs to critically consider the heterogeneity and mobility of the human population in the specified environment, and the socioeconomic and political influences that are likely to shape the level and extent of community commitment to participate. Programs might need to consult or fully integrate existing and influential local committees such as the health and environmental (HEC) as well as Health Facility Committees (HFC), as these are likely to dictate levels of community involvement. They may also be ideal centres of local knowledge and influence for managing the daily implementation of the intervention and dealing with subtle issues at such fine scales where the intervention operates.

6.3 The CORPs' experience of public health delivery: lessons learned for future malaria control programs

The overall implications of the findings in chapter 3 would suggest that there are important differences in perceptions of participation between the program management levels and community members. As such, strategies are required to mobilize greater community support and promote good communication among residents. Moreover, with reference to UMCP, the fundamental challenge highlighted in chapter 3 is that the

CORPs understood their contribution to the UMCP as a 'job' rather than 'voluntary participation'. There is therefore an important need to understand how general public perceptions about their involvement in public health programmes affects decisions for intervention uptake or implementation at local, regional and even national level. While, in some cases, the CORPs' familiarity and ability to identify with local residents facilitated their performance (chapters 2 and 3), in many others, perceived lack of an official mandate from a recognized central body undermined their authority to mobilise community compliance.

The observation from chapter 3 that within UMCP individual's ability to detect breeding habitats was reduced when they were recruited by program staff instead of local leaders highlights quite significant opportunities for improvement in systems through which these human resources are identified, mobilized and maintained. Future implementation strategies should emphasize the need for local government ownership and control of the recruitment process at the grass roots, rather than municipal level. The questions of who recruits, and who gets recruited, should guide the planning and design of these programs much earlier in the process of institutionalization. These findings confirm those of others (Oakley 1989a, Okanurak *et al.* 1992) regarding the need for engaging the local resident communities in health development programs but also go further by suggesting who should lead in the recruitment process. A remaining limitation of this study is that it does not provide guidelines as to how best to achieve this in practice. Overall these findings outline a picture of mediocre performance and imply an urgent need for equipping these, and other similar local community personnel, with skills to effectively communicate and engage the whole community in their optimization of intervention impact. It is therefore significant that while malaria vector control training programmes focus on improving technical skills, such as the ability to detect and classify larvae (Chapters 2&3) for LSM, increased emphasis should also be placed on improving individuals' communication skills to enable them interact more extensively and effectively with the rest of the community particularly where they are expected to induce essential behavioral change such as an "open door" response to the programme.

6.4 Surveillance and early management platforms for effective and sustainable larviciding work

For the UMCP the distinction between contracted employees and paid volunteers is not incidental: it was the involvement of these modestly-paid and basically-trained community-members as casual labourers that assured the programme's affordability and sustainability (Fillinger *et al.* 2008, Geissbuhler *et al.* 2009, Mukabana *et al.* 2006). In the past, the success of larval control campaigns has always hinged on manpower, a readily available and highly mobile work force exclusively committed to seeking out and treating or destroying vector breeding habitats (Gorgas 1915, Kelly 2011, Soper and Wilson 1943, Watson 1953). However, public resources are severely limited in most malaria-endemic developing countries. In Dar es Salaam, specifically the city council and its respective municipalities could not absorb the cost of a formally employed full-time larval control task force. That said, the move from civil participation to informal employment carries a more profound significance in the Tanzanian context and the same is probably true for many other countries south of the Sahara. The ambition of Nyerere's government to promote development through mass participation has cast a long shadow on popular enthusiasm for community-based development initiatives. While today development and public health professionals speak of *participation* as a means to empower communities, in Tanzania the term has historically implied the provision of free labour (Marsland 2006). Thus, the community-based role of the CORPs, working under the municipalities while not formally employed by them, might have had particularly negative impact on their performance and the program as a whole, and, in the long run, it may lead to apathy rather than enthusiasm.

One of the more successful aspects in Nyerere's plan for national development was the control of malaria through intensive, community-based environmental management strategies directed towards drainage or the destruction of mosquito habitats (Clyde 1967). In this instance, participation entailed a commitment to the nation, demonstrated through routine practices of living. *In lieu* of formalising their role within the municipalities, one way to legitimize the work of the CORPs might be to integrate larval control more fully with informal networks of maintenance service provision organized at the ward or *Mtaa* level. Community-based participation is deemed an essential aspect in public health service delivery: the assumption is that, by being involved in the planning and implementation of interventions, citizens can take ownership of the technologies and practices that impact their lives. Exploring the CORPs' day-to-day experiences points to how grassroots participation is a negotiation between overlapping, yet often distinct, municipal and communal bodies. Rather than merely representatives of the community, volunteers in public health programs act as mediators between everyday communal concerns, the local government action and the financial constraints of responsible institutions. So much so that, the success of the UMCP in reducing malaria prevalence depended on the capabilities and motivation of the CORPs to gain access to breeding habitats. More than merely manual labour, routine surveillance and control entailed traversing boundaries between public and private spaces through building relationships and establishing trust with local leaders and residents (see chapter 5). Therefore integration of such responsibilities into local government structures and functions, as part of their routine responsibilities, may well enhance acceptance and performance.

The UMCP scientific team was successful in developing the CORPs' technical capacity to recognize different breeding grounds and identify mosquitoes (Chaki *et al.* 2011, Chaki *et al.* 2009, Dongus *et al.* 2010, Vanek *et al.* 2006). The program achieved encouraging early success (Dongus *et al.* 2011b, Geissbuhler *et al.* 2009) and led to increased resources for wide-scale implementation of LSM in urban Dar es Salaam and the establishment of a sustainable internally-funded program implemented by the national MOHSW (chapter 5). However, it is worth mentioning here that enhancing such social capital within the time-frame and funding constraints of such a complex programme was considerably more difficult. Therefore in chapter 5 we critically analysed how this institutional development process was realized by focusing on the relationships between the various entities of public health interventions and the institutional landscapes in which the UMCP was located. As the findings in chapters 3 and 5 suggest, effective participation of all the stakeholders required not only the technical capacity but also essential national and local institutional support, both in terms of providing them with a broadly recognized identity and recognizing the value and role of their individual contributions. Furthermore, critical to advancing these discussions, is an understanding of the histories and meanings of participation within the particular contexts in which these specific activities took place. Reflecting upon UMCP's experience with LSM is the integration of this traditionally vertically-managed vector control activity into a decentralized community-based implementation system that enabled the program to grow into what it is today. Although community engagement has made a major contribution in terms of general program affordability and sustainability, it is the clear hierarchical structure associated with vertical organization of this community based management system, as well as the clear distinction in the lines of responsibilities across the various scales within UMCP, which contributed most to its evolution and subsequent growth. For the UMCP, the central coordination role taken by the city council enabled institutionalization of strengthened management and planning, improved community-mobilization capability, and the overall capacity to exploit national and international funding systems. Furthermore, each level of management within UMCP is responsible for identifying and addressing operational shortcomings in a well coordinated manner. Furthermore, whereas several other studies have linked health sector decentralization with reduced health expertise (Buchan 2000, Dovlo 2004, Kritski and Ruffino-Netto 2000, Zimmerman 1992), the current UMCP has exhibited rather stable career development and growth of distinct professional cadres at these complementary and very different institutional bases. Critically, this has been possible because of the strong collaborations between the local government and research partners, as well as the high degree of program ownership by the city council and three municipalities, coupled with catalytic donor funding and technical support from expert overseas partners. This study therefore sheds some light on the ways in which the material and institutional set up of pilot evaluation programmes can be optimized to facilitate the creation of public spaces, and triggers new occasions for participation in public health planning and delivery. As the findings in chapters 2, 3 and 5 demonstrated for the UMCP, community-based malaria control is embedded in a complex of relations including ecology of larvae dippers, blocked drains, tin cans, fences and gates, sketch maps and plots all of which are framed within much larger geographic, political and institutional structures.

As chapter 5 illustrates for LSM by the UMCP in Dar es Salaam, or any public health programmes are guided by relationships at all levels of management and implementation processes. These occur within cadres or among individuals and institutions, as witnessed within UMCP at the interfaces between community-based implementation personnel, local government managers and their technical support partners at research institutions (chapter 5). The most important lessons to be learned by both the local program and the global public health community relate to these relations can be managed so that the specific challenges at each of these interfaces is overcome. First of all, it should be clearly agreed what role and level of involvement each stakeholder should have in each facet of the program. For example, direct involvement of scientific staff in training, monitoring and management activities as technical advisors can undermine the autonomy, leadership, morale and stakeholdership of a government-run programme if not carefully phased out during the transition from pilot evaluation to sustained programme. Aslo, such artificial external inputs influence the fundamental nature of the evidence derived from impact evaluations emphasizing the need to carefully manage the role of supporting expert partners throughout the development of such public health service programs (Habicht *et al.* 1999). Our experience has been that maintaining these relationships is as strategically and vitally important as it is challenging. A lucid understanding of how these complementary roles are aligned, and a commitment to sustain them, is therefore essential to cultivate on both sides of all interfaces and among high level oversight partners.

6.5 The role of independent evaluation and routine monitoring of adult mosquito population and the future of vector control

Intensive and extensive monitoring of adult mosquitoes in response to LSM programmes is of critical importance in identifying and addressing coverage gaps and operational challenges. With larviciding these gaps usually occur unpredictably within narrow spatial and temporal scales. As such it is important that the distribution of adult mosquito sampling locations more-or-less matches those of personnel responsible for the application of larvicides, so as to assess personal performance and help improve the effectiveness of the control program as a whole. This is due to the fact that, apart from the efficacy of larvicides, the success of larviciding relies more on personal sensitivity of detection and treatment of all potential larval habitat (Chapters 2 and 3). Conventional centralized surveillance systems that rely on trained epidemiologists and/or entomologists to visit sites to survey mosquitoes and human cases may be constrained by logistical and financial barriers to surveying so many locations so frequently. Borrowing from past successful vector control experiences, we find some fascinating parallels with the UMCP monitoring and evaluation strategy and those applied in Brazil more than 70 years ago. In Brazil, a centralized larval surveillance system and adult mosquito monitoring system were deployed to independently evaluate the quality of work by the larval inspectors (Ross 1902, Soper and Wilson 1943) coupled to a more response oriented local monitoring system for all the anti-larval and adult mosquito teams at district levels. In the Zambian Copper Belt, vector densities and malaria incidence rates were used to monitor and appropriately tune environmental management strategies (Utzinger *et al.* 2002b, Watson 1953). More recent vector control programmes though not based on LSM, have also strongly emphasized on the need for good surveillance systems that work best in vertically-decentralized manner (Chanda *et al.* 2008, Impoinvil *et al.* 2007). The absence of mosquito surveillance has been incriminated as limiting to the success of most urban malaria vector control initiatives (Impoinvil *et al.* 2007).

For UMCP, the need for much better surveillance systems was realized at the very beginning of the program following reports of poor performance of the surveillance CORPs (Vanek *et al.* 2006). Critically looking at the much broader political history and governance structure of Tanzania and Dar es Salaam specifically, presents lots of opportunities for effective community participation in mosquito surveillance and control (Chapter 5). However, it should be noted that community-based surveillance alone does not guarantee improvement of the surveillance system and that chapters 2 and 3 document clear examples where it has failed. The fact that the internal quality control teams mechanisms (Fillinger *et al.* 2008) within the UMCP failed to detect most of the shortcomings reported in chapters 2 and 3, emphasizes the need for formally institutionalizing independent surveillance systems that would be responsible for critically identifying and addressing all process indicators to the management on time.

There are a number of key issues that need to be taken care of to harness the full potential of community-based surveillance systems. The first important step I recommend is to examine the recruitment, training, supervision, management and incentive systems for community-based personnel. Furthermore, improved communication strategies for other members of the community at large should also be evaluated as a means to engage them in as active agents and supportive stakeholders to improve upon intervention access and communication with expert community. The second important step is to develop appropriate linkages and collaborations among various cadres of players. House/plot owners who are asked to voluntarily enable access to favorable breeding habitats, the local government leaders who select the volunteers as well as politicians, funders and experts who support the programme.

In chapter 4 a community-based surveillance system of adult mosquitoes using ITT with no supervision from the research team proved the most cost-effective, safe and epidemiologically relevant way to monitor adult malaria vector mosquitoes. This was achieved despite the relatively low sensitivity of the ITT and all the operational challenges associated with sustaining such a large team of volunteers on such an unprecedented scale of operations. So what are the features that make this system so successful and different from other community-based longitudinal adult mosquito monitoring surveys? The most direct explanation is the ability to conduct longitudinal sampling on a monthly temporal cycle that is sufficient frequent to capture seasonal variation in vector density at hundreds of locations (Chapter 4). Such community-based surveillance systems for adult mosquito populations might easily be implemented with more sensitive, practical, alternative trapping technologies in the future to enable mapping of residual vector populations and targeted vector control with LSM or other approaches that complement LLINs or IRS. Most conventional trapping methods applied to research achieve limited spatial and temporal coverage due to reliance upon electricity supply and specialist personnel. Trap designs like the ITT, which may have significant limitations but do allow tapping into the highly underutilized, cost-effective human resource available through community-based recruitment in most resource-poor countries, may therefore have utility as monitoring tools for large scale programmes.

Apart from the community engagement approach to adult mosquito surveillance system to support LSM of UMCP (Chapter 4) and IRS elsewhere in Africa (Abilio 2010, Sharp *et al.* 2007a, Sharp *et al.* 2007b), the other innovative feature of this system is the independent, carefully controlled quality assurance surveys of a subsample of the weekly routine community surveys. The results of these surveys were rather reassuring in quality, coverage and overall effectiveness that it confirmed those of the unsupervised community-based surveys. Since quality of routine health-related data is questionable in most developing countries, quality assurance mechanisms such as these are of paramount importance, to not only generate reliable information but also confidence in the evidence it constitutes. Therefore, as the global malaria elimination initiative (Campbell 2008, Feachem *et al.* 2010, Greenwood 2008a, Greenwood *et al.* 2008, Roberts and Enserink 2007, Tanner and Savigny 2008) progresses, such spatially extensive and longitudinal CB systems for monitoring vector populations, will become increasingly useful for characterizing sparse residual mosquito populations across large areas and for monitoring and evaluating impact of supplementary vector control interventions upon them. The current CB mosquito surveillance system described here sets up a benchmark for how such systems can operate in practice, but future programs will need to capitalize on improved trap technologies that will ideally, no longer require a human being as bait. Such technologies should be more sensitive, less bulky, less expensive, and should readily trap the outdoor-biting, zoophagic mosquito species that are increasingly dominating residual transmission across the tropics (Bayoh *et al.* 2010, Bugoro *et al.* 2011, Reddy *et al.* 2011, Russell *et al.* 2011a).

6.6 Beyond mosquito surveillance: Remaining delivery, surveillance and management challenges for LSM programmes

LSM through larviciding has the advantage of suppressing malaria vectors at the larval stage before they become adults and spread disease (Fillinger and Lindsay 2006, Geissbuhler *et al.* 2009, Shililu *et al.* 2007, Shililu *et al.* 2003). This historical approach has led to elimination of malaria in some ecosystems similar to those where malaria is endemic in Africa today, therefore raising hopes that this approach might be a valid tool to consider in these areas. The most important determinant of success with sustained larvicide application is efficient organization, management and monitoring of the implementation process. Comprehensive, constantly updated knowledge of vector breeding site distribution is essential and it would be ideal to target larviciding efforts at the most productive habitats. While the microbial larvicides used by the UMCP as described here are highly efficient and specific without causing adverse effects to non-target organisms, such programmes could only benefit from the availability of alternative agents which can persist longer in the environment. Despite the success of the current UMCP (Fillinger *et al.* 2008, Geissbuhler *et al.* 2009), there are a number of challenges that remain to be addressed and need to be considered by future programs.

One of the very big challenges that has been experienced with this program and shared with many pilot studies elsewhere in Africa is the failure to achieve reductions in adult mosquito density that are comparable with those apparently documented for larval density. In Dar es Salaam, only a 31% reduction in adult densities of the primary vector of malaria was observed following one year of community-based larviciding in urban Dar es Salaam, despite the reported over 90% reduction in larvae density (Fillinger *et al.* 2008, Geissbuhler *et al.* 2009). Similarly only 28% reduction in *An. gambiae s.l.* adult density was observed in The Gambia, despite evidence for a 90% reduction in mosquito larval density due to larviciding (Majambere *et al.* 2007, Majambere *et al.* 2010). While direct interpretation of these data at face value might suggest such exotic biological explanations as massive levels of adult vector immigration (Killeen *et al.* 2003, Service 1997) or density-dependent population regulation (Russell *et al.* 2011b, White *et al.* 2011), the chapters 2 and 3 strongly support the view that larval abundance indicators are often grossly inaccurate and have no place in objective impact evaluation. As shown in chapter 2, not only was the detection of *Anopheles* larvae extremely poor, it is also biased to exaggerate the success of larvicide impact. Larval surveillance data should therefore only be used for operational monitoring of larval-stage suppression to detect failures in application coverage and quality on a day-to-day, fine-scale basis. Beyond the consistently poor quality of all the larval surveillance indicators evaluated, the most obvious limitation of larval population surveys is that they are biased to exaggerate LSM impact because applied only to the habitats that are known to the personnel responsible for surveillance and, presumably, the application of larvicides.

It can be argued that the key to the development of sustainable malaria control programs through LSM is the availability of reliable process indicators of intervention coverage and quality that can be directly related to outcome and impact measures such as vector population density and malaria prevalence, incidence and mortality among human residents. With most priority malaria control interventions their progress and impact indicators are widely defined and can be monitored and evaluated using a combination of epidemiological (routine surveillance of cases and deaths) and entomological indicators and tools to enhance evidence based implementation and rational use of available resources. With the development of tools such as biomarkers (PCR and Serology) of transmission and improved diagnostics (RDTs) as well as processes to track the various parasitological indices such as the nationally representative surveys such as Demographic and Health surveys (DHS), Malaria Indicator Surveys (MIS) such surveys provide periodic useful accurate assessment on the quality and coverage of malaria interventions (Breman *et al.* 2004, de Savigny and Binka 2004, Guerra *et al.* 2008, Keating *et al.* 2009, Moody 2002). Common traditional indices for monitoring progress and impact of malaria control interventions include parasite prevalence surveys of a randomly sampled population, malaria incidence through passive examination of suspected, usually febrile cases presenting routinely at health facilities coupled with active detection of fever cases through community or household level visits and morbidity and mortality determined through routine surveillance. Furthermore, in the context of existing priority malaria vector control interventions the presence of clearly defined process indicators such as LLIN or IRS coverage that can be easily tracked at household level as well as utilizing existing platforms like the demographic surveillance systems (DSS) as well as various assay kits for detecting susceptibility and resistance to insecticides, have dramatically enhanced the wide and rapid scale up of these interventions. On the other hand however, with LSM these are either poorly developed or not present at all. The only process indicators for routine monitoring of LSM programs are the habitat and larval abundances, with adult mosquito densities serving as the sole rigorous impact indicator. However, the tracking of these process indicators is often very difficult and inconsistent thus larval surveillance alone is inadequate and unreliable because it only reflects observations in habitats successfully covered by surveillance activities and has a high tendency of introducing biased reporting as noted in chapters 2 and 3. As such weekly monitoring of adult mosquitoes is necessary to allow rigorous monitoring, evaluation and management practices. Chapter 4 in this study provides further emphasis on the need of intensive and extensive surveys of these adult mosquitos in order to not only measure but characterize transmission dynamics. On the other hand while clinical or parasitological indices are essential for rigorous evaluation of program impact, these are usually collected and reported on timescales too slow to enable day-to-day management for optimal performance of LSM program, therefore such epidemiology predictive longitudinal surveys stand a high chance of informing evidence-based implementation and resource allocation.

In addition to having epidemiological predictive power, a balanced set of process indicators will need to serve both the monitoring and evaluation needs of LSM programmes. Indicators selected for monitoring will probably be slightly different from those needed for evaluation, depending on the reporting timeframe and level within the health system. For instance, more information is required much faster, with much finer spatial resolution for project management at local level than is needed at national or international levels, so the number of indicators reported should decrease substantially from the district to the national and international levels. The shorter list of indicators which are used for programme evaluation rather than monitoring should focus primarily on outcomes and impact rather than processes and should be objectively collected, independently of the responsible implementation teams wherever possible. Moreover, improving the levels of impact such evaluations can document requires the development of process indicators and reporting systems that can improve the speed and sensitivity of detection and response of implementation failures. Based on the experience described in chapters 2 and 3 in which large quantities of laboriously compiled larval abundance indicators were poorly collected and rarely acted upon, it is clear that it is essential to simplifying the collation and reporting process by reduce the amount of paperwork involved to allow simpler, easier and more direct follow up by program managers. It is therefore essential to adopt mobile phone-based surveillance reporting and automated server-based archiving and synthesis can allow real time access to not only the data itself but also the information it conveys. Investment in the development of such broadly applicable tools and indicators could enable affordable community-based integrated vector management to be achieved and sustained in a variety of settings across sub Saharan Africa.

Perhaps the obvious indicator that is obviously missing from the portfolio of LSM programmes is simply coverage. Unlike LLINs, IRS or a personal protection measure, to my knowledge no LSM programme has neither clearly defined nor reported any indicator of coverage with the intervention itself let alone tools for measuring those indicators, rather than with follow-up monitoring surveys as described in chapters 2 and 3. The only indicators are the most obvious larvicide carrier and traces of granules in treated water bodies (Figure 6.3), as such the management of these programs is extremely difficult. The experience of the UMCP suggests that these visually obvious carrier granules offer an opportunity to directly estimate coverage and that this characteristic should be considered as an important component of the target product profiles of larvicides for routine programmatic use. The microbial larvicide products used by the UMCP included both a water-dispersible granule (WG) formulation for liquid application with knapsack sprayers and corn granule (CG) formulations for hand application. Whereas the WG formulation is stored as a dry product and mixed into water for spraying as a liquid onto open habitats with low vegetation where the microbials can reach water surface, the granular formulation (Figure 6.2) is a dry granule that is particularly ideal for habitats with emergent tall vegetation. While the system used by the program for monitoring the progress and success of larviciding (Fillinger *et al.* 2008) overwhelmingly failed to identify sites that might have been missed by the larviciding teams, presumably because of the difficulty of detecting late-stage larvae, the granular formula serves as a readily visualized, direct internal marker for coverage of because it leaves behind the traces of granules which can be used to distinguish between treated and untreated habitats.

Figure 6.2: Application of microbial larvicide granules displayed on palm (*Bacillus thuringiensis var israeliensis*) by the UMCP CORP.

Beyond visualization of the inert carrier, potent larvicides with longer residual efficacy might enable such elegant delivery strategies as auto dissemination by mosquitoes themselves (Devine and Killeen 2010), as has been achieved for *Aedes aegypti* in Peru (Devine *et al.* 2009). One particularly obvious candidate active ingredient for larvicide autodissemination is the insect growth regulator pyriproxifen with extraordinary potency and long residual effect (Braga *et al.* 2005, Darabi *et al.* 2011, Nayar *et al.* 2002, Sihuincha *et al.* 2005, Yapabandara and Curtis 2002, Yapabandara *et al.* 2001). While this study examined a programme based on the traditional, low technology approach of manual application, the auto dissemination approach for delivering larvicides deserves consideration and is may address the challenge of achieving high coverage, particularly of inaccessible or cryptic water bodies which might not be easy to locate. In addition, an autodissemination strategy might be expected to have a twofold advantage: first would lead to improved delivery of the larvicides to only those habitats that mosquito prefer laying their eggs. Secondly, this precise larvicide dissemination by the vectors themselves would dramatically reduce the current operational costs associated with delivery and surveillance due to reduced number of personnel.

Figure 6.3: Traces of *Bacillus thuringiensis var israeliensis* granules in a breeding habitat sprayed by UMCP CORP

Perhaps the greatest challenge to effective engagement of communities in vector control programme implementation (Mukabana *et al.* 2006, Service 1993a) is the need to meet community expectations based on their perceptions of impact while also keeping track of objective indicators of impact. Often the relationship between malaria, mosquito species and habitats is usually poorly understood in local communities (Mutuku *et al.* 2006, Opiyo *et al.* 2007) and mosquitoes are often seen as a nuisance more than a disease vector (Adongo *et al.* 2005, Klein *et al.* 1995, Minja *et al.* 2001, Schellenberg *et al.* 1999). Therefore a LSM programme that does not reduce the densities of the non-malaria-transmitting Culicine mosquitoes that dominate human biting nuisance in Dar es Salaam and most of rural Africa is less likely to be received with enthusiasm by the community (Stephens *et al.* 1995) and therefore becomes extremely difficult to mobilize community support for such interventions over many years. My closing suggestion is therefore that LSM programmes should therefore extend their operational activities and funding base to embrace control of all major human-biting mosquitoes of local relevance and all the common pathogens they can potentially transmit.

6.7 Summary recommendations and implications of the research findings for malaria control policy in Africa

Summarizing this discussions on community-based larval source management (LSM) that this thesis advocates to compliment current malaria vector control measures such as IRS and LLINs, it is important to: First of all recognize that LSM includes several other techniques besides repeated application of *larvicides* to aquatic larval habitats including drainage and filling of flooded depressions, flushing of streams, and salinity control in coastal areas. All these are just simple methods that can be accomplished with local labor and resources. Secondly I would like to highlight the fact that there is plenty of historical evidence that these various LSM strategies were successfully deployed in many tropical and semi-tropical areas leading to the suppression of malaria. Even though detailed recommendations relevant to each of the aspects of this study are already included in the relevant chapters, the key issues pertaining to the specific program and at Country/policy levels are summarised into the following points below:

SUMMARY RECCOMMENDATIONS AT PROGRAMMES-LEVEL:

OPPORTUNITIES:

- Community involvement in both the recruitment process of the individuals and implementation of the intervention. This enabled wider community awareness and participation and improved individual performance.

- The LSM program originated at 'grassroots level' by local municipal government, which then gradually evolved into the Urban Malaria Control Program supported by academic institutions and the government. This helped to increase ownership of the programme and accountability of the participating individuals and institutions.

- Decentralized vertical management structure. The programme incorporated a Centralized vertical management of community-based implementation systems, utilizing the hierarchical gradient of implementation strategies and partner roles across all the necessary spatial scales. The central coordination role by the city council immensely enabled the institutionalization of strengthened management and planning, improved community mobilization capability, and capacity to exploit national and international funding systems as well as establishment of a sustainable implementation program.

- Effective communication and feedback mechanisms formed part and parcel of the day-to-day implementation of the LSM operations. Feedback within days, weeks or months rather than years. This enables effective and prompt decisions and actions by the management and implementing carders.

- Surveillance systems built up slowly to achieve the standards required. Separate and independent monitoring and evaluation system reporting directly to the programme management on larval surveillance, adult surveillance and larvicide application as well as the performance of individual volunteers. This was necessary since the internal quality control mechanisms could not deal with the pressures of self assessment of the internal process indicators.

- Decentralized, community-based use of the ITT-C was the most cost-effective and epidemiologically relevant way to monitor adult malaria vector mosquitoes.

CHALLANGES

- Some residents do not allow larviciding teams to access habitats in their compounds. The, key challange for mosquito control programs focusing on larviciding in urban areas is to have full, regular access to all open spaces potential for accommodating aquatic habitats where mosquito proliferation takes place including all fenced plots and other areas with restricted access for the public. This requires substantive and open collaboration between stakeholders.

- All mosquito species must be targeted to reduce nuisance biting and maintain community support. Need to meet community expectations based on their perceptions of impact to whom the relationship between malaria, mosquito species and habitats is usually poorly understood in local communities and mosquitoes are often seen as a nuisance more than a disease vector

- Weekly treatment of breeding sites is required because the larvicides used have low residual efficacy as a result the whole intervention becomes too costly with personnel and operational charges. The UMCP and similar such programmes could only benefit from the availability of alternative agents which can persist longer in the environment.

- Close supervision of larviciding teams is required to constantly monitor their work performance.

- Need for carefully incorporating independent quality assurance surveys as process indicators for larval control programmes. This is necessary to reduce biases in the perspectives or supervision practices of the supervisors with the competing interest of being responsible for larvicide application and surveillance

- LSM requires continuous and thorough monitoring is required because success and failure occurs on remarkably fine spatial (< $1km^2$) and temporal scales (1 week) that match to the retreatment cycles and geographic division of responsibility to individual staff.

- Achieving sustainability is an ongoing challenge for LSM programmes. Key leason to such programmes is how best to plan so that implementing and monitoring functions remain distinct and quality assured, yet integral, of the program.

- Concurrent malaria control interventions and the lack of well defined impact indicators complicate the measurement of the impact of LSM.

RECOMMENDATIONS FOR COUNTRY AND POLICY LEVEL:

1. While clearly demonstrated that LSM is very much a strategy that needs to be tailored to each setting based on local environmental conditions, the more direct country specific implication would be- that any country considering this should start small on pilot scales and gradually building and institutionalizing their capacity and experience from there. Being a programme building rather than maintenance exercise, the training and developments costs should be on the budget plan. LSM therefore needs more than just current funding and political support but rather the strategic, long term variety so that local programmes and supporting institutions have time to learn, consolidate and stabilize.

2. The command structure for LSM as demonstrated here requires an integrated management structure with monitoring, evaluation and management tools appropriately aligned to the tasks at hand, in particular at the interfaces between the various actors (chapter 5). This calls for a much proper institutionalization plan at programme inception. It is extremely important to decide who will do what at what spatial scale and how the multiple institutions will interact. This is a key step most people and programmes overlook and don't put enough effort into it with the result that everyone takes responsibility for success and but can readily offload responsibility for failure. This diffusion of roles and responsibilities inevitably results in i) competition between the technical and oversight partners, ii) politicization of the technical partners at the expense of doing their day-to-day technical work, and iii) a disconnect with the partners in other sectors, especially the local government.

3. Management capacity is by far even more important at this juncture than entomological capacity. One of the strengths of particular importance for evidence-based LSM programmes implementation is the ability to collate, synthesize and report monitoring data in the shortest time possible more precisely in days rather than weeks on meaningful programmatic scales. Results from chapters 2 and 3 have demonstrated that the entomological expertise required is often not insurmountable but large scale programme management of logistics and human resources is usually the most limiting capacity.

4. Beyond the poor quality of all the larval surveillance indicators evaluated here, the most obvious limitation of larval population surveys is that they are biased to exaggerate LSM impact because applied only to the habitats that are known to the personnel responsible for surveillance and, presumably, the application of larvicides. Similar to prevalence surveys that loose all usefulness at programmatic scales when sample sizes get diluted out into a total study population of <100,000 people, larval abundance indicators are often grossly inaccurate and the data becomes highly unreliable when working on meaningful programmatic scales and have no place in objective impact evaluation. In either case one ends up with detailed information about a minority of the population living in the samples clusters and heterogeneity occurs on far too fine a scale to extrapolate between

them so essentially the unsampled population remains a mystery. As the results have shown, not only was the detection of *Anopheles* larvae extremely poor, it is also biased to exaggerate the success of larvicide impact. Larval surveillance data should therefore only be used for operational monitoring of larval-stage suppression to detect failures in application coverage and quality on a day-to-day, fine-scale basis.

5 Efforts should be directed at to the development of reliable process indicators of intervention coverage and quality that can be directly related to outcome and impact measures such as vector population density and malaria prevalence, incidence and mortality among human residents to support sustainable malaria control programs through LSM. This has to go together with introducing rigorous external quality control of the internal process indicators.

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APPENDICES

Appendix 1:

Municipal mosquito larval habitat spotcheck-Open habitats

Serial number on the map form_______________________________________

Date:_______/_______/_________

Municipal:_________________________ Ward:________________________ Mtaa:___________________________ 10-cell unit :_____________________ 10-cell leader ___________________

GPS (UTM/WGS84) : Northing_________________ Easting______________________

	Yes	No
Is there a map		
Is the map accurate		
Does the map match city copy		

Habitat codes:

1: puddles/tire tracks
2: Swampy areas
3: Mangrove Swampy
4: Drain/ditch
5: construction pits/foundation/man-made holes
6:water storage &any other man made container
7: Rice paddy
8: Matuta
9: Other agriculture
10:Stream/river bed
11:Pond
12: Others (describe below)

Plot ID	House No.	Habitat ID	Habitat type	Is habitat type correct?	Correct habitat type	Habitat found by the CORPs 1=Yes, 2=No	Habitat Description	wet?		Habitat perimeter			Plants				water depth		Larval Stage Anoph.			Larval Stage Culex			Pupae		**last application of larvicide as per timetable**	Is there any fence wall 1=Yes, 2=No	Does CORP go to these plots 1=Yes, 2=No	**Comments**
								dry	contains water	< 10 m	10-100 m	> 100 m	None	Short vegetation	Tall vegetation	Floating vegetation	<0.5m	>0.5m	Absent	Early	Late	Absent	Early	Late	Absent	Present				

Supervisors signature____

Appendix 2:

Municipality: [ ], Ward: [ ], *Mtaa*: [ ], TCU: [ ], [ ], [ ], [ ], [ ]

Interviewer: ____ Date: [/ /]

Identification

Use the following codification: I=Ilala, T=Temeke, K=Kinondoni

Use the following codification:

ILALA	KINONDONI	TEMEKE
1-Buguruni	1-Magomeni	1-Azimio
2-Ilala	2-Mikocheni	2-Keko
3-Kipawa	3-Mwananyamala	3-Kurasini
4-Mchikichini	4-Mzimuni	4-Miburani
5-Vingunguti	5-Ndugumbi	5-Mtoni

Yes=1   No = 2, No answer = -99

CORPs' questionnaire

1. Gender of the respondent   F= 1, M= 2   [   ]

2. How old are you in years?   [   ]

3. What is your education level?
   - Did not attend school at all = 1
   - Standard seven = 2
   - Form four = 3
   - Form six = 4
   - No answer = -99   [   ]

4. Did you hear of Urban Malaria Control Program, before you started working for it?   [   ]
   Yes=1, No= 2, No answer= -99

5. Do you know what it stands for?
   - Not at all = 1
   - Partially = 2
   - Yes completely = 3   [   ]
   - No answer = -99

6. How did you first get to know about UMCP?
   - Meeting = 1
   - Workshop = 2
   - Media e.g. newspaper, radio, television = 3
   - From a friend or neighbor = 4
   - Other = 5, please specify………………
   - No answer = -99   [   ]

7. Could you please describe the objectives of the program?
   (Interviewer tick as relevant from the list)
   - [   ] control of cholera
   - [   ] help the citizens to clean their environments

[ ] control of Malaria
[ ] control of filariasis
[ ] control of mosquitoes
[ ] other specify……………..

8. How long have you been with the programme **[ ]**

1-5 months	=1
6-12 months	=2
13-18 months	=3
More than 18 months	=4
No answer	= -99

9. How did you join the programme? **[ ]**

Chosen by street leaders	= 1	
Chosen by project administrative staff	= 2	
Chosen by ward supervisor	= 3	
Other	= 4	Specify……………………………………
No answer	= -99	

10. When you joined the program did you receive training? [ ]
Yes=1, No= 2, No answer = -99
(*If* ***Yes,*** *go to Q 11, if* **No** *go to Q.16)*

11. From whom did you receive your initial training?
(Mark all that apply)
[ ] Project staff from city level
[ ] Municipal coordinators
[ ] Project Inspector
[ ] Ward supervisor
[ ] A fellow CORP
[ ] No answer

12. From whom did you receive your subsequent training?
(*Mark all that apply*)
[ ] Project staff from city level
[ ] Municipal coordinators
[ ] Project Inspector
[ ] Ward supervisor
[ ] A fellow CORP
[ ] No answer

13. What type of training did you get?
Mark all that apply
[ ] seminar/workshop
[ ] field/site training

[ ] reading materials (e.g. brochures, field guide books, leaflets ect.)
[ ] other, specify
[ ] No answer

14. How often do you receive training now days?

I never receive any further training =1
Less than once a month =2 [ ]
Once a month =3
Once a week =4
More than once a month =5
No answer =-99

15. With the different types of training you are receiving how would you rate them in terms of usefulness for your job performance?

(1=very poor, 2=poor, 3= moderate, 4= good, 5= very good)
Seminar/workshop [ ]
Reading materials [ ]
Field/on site trainings [ ]
Other [ ]

16. Would you like to have more training? [ ]

Yes=1, No= 2, No answer = -99

17. How many hours do you spend on UMCP activities per day? [ ]

18. How often do you get accompanied by your supervisor in your field work?

Not at all = 1
Less than once per month = 2
Once per month = 3
Once per week = 4 [ ]
More than once per week = 5
No answer = -99

19. How often do you get visited by your inspector?

Not at all = 1
Less than once a month = 2 [ ]
Once a month = 3
Once per week = 4
More than once per week = 5
No answer =-99

20. Do you have any other income generating activities besides UMCP? [ ]

Yes=1, No= 2, No answer= -99

(If Yes, go to qn.21, if No go to qn.23)

21. What kind of activities

(*Mark all that apply*

[ ] Farmer
[ ] Laborer
[ ] Informal sector
[ ] Business
[ ] Fisher
[ ] Government or formal sector employment
[ ] Other, please specify:……………………………………..
[ ] No answer

22. On average how many hours per day do you spend on those activities? [ ]

23. Is your home

Outside the ward you are working =1
Within the Ward but outside the *Mtaa* you are working =2 [ ]
Within the *Mtaa* but not your area of responsibility = 3
Within your area of responsibility where you work as a CORP for the UMCP = 4

24. For how long have you been staying in that house/place?

Less than six months =1
6-12 months =2
More than 1year but less than 5 years =3 [ ]
Five years or more =4
No answer = -99

25. How long do you take to travel from your home to reach the ward of your activity?

1-15 minutes =1
16-30 minutes =2
31-60minutes =3 [ ]
More than one hour =4
No answer = -99

26. How long do you take to travel from ward offices to reach the specific area of your activity?

1-15 minutes =1
16-30 minutes =2
31-60minutes =3 [ ]
More than one hour =4
No answer = -99

27. How would you describe the relationship with community members in the area of operation
towards your activities for the *UMCP*.

They are actively disruptive/hostile =1
They don't accept nor support =2
They are accepting but not supportive =3 [ ]
They are reasonably supportive =4
They are very supportive =5
No answer =-99

28. How would you describe the relationship with *TCU* and Street leaders in the area of operation
towards your activities for the UMCP.
They are actively disruptive/hostile =1
They don't accept nor support =2
They are accepting but not supportive =3 [ ]
They are reasonably supportive =4
They are very supportive =5
No answer =-99

29. How do you rate your relationship with the UMCP ward supervisor?
Very poor =1 good =4
Poor =2 very good =5
Reasonable =3 No answer =-99

30. What are reasons for?
a)Reasons for negative perceptions
Mark all that apply
He/She is paid more [ ]
Not supportive [ ]
Rarely goes to the field with the CORPs [ ]
Any other [ ] please specify………
No answer [ ]

b) Reasons for positive perception
Mark all that apply
Very supportive [ ]
He/she is coming from same ward [ ]
His/her living standard matches yours [ ]
He/she frequently accompanies you to the field [ ]
Any other [ ] please specify………….
No answer [ ]

31. Have you worked with any similar programs, if so please describe your impression of the standard of services each provided.

Yes=1, No= 2, No answer= -99 [ ]

Very poor =1 poor = 2 Average =3

Good =4	Excellent =5
Care International	[ ]
Water Aid	[ ]
JICA	[ ]
Plan international	[ ]
World Vision	[ ]
IMPACT	[ ]
……………..	[ ]
……………..	[ ]

Appendix 3:

Standardized UMCP forms for routine adult mosquito surveillance teams to help control for and minimize data fabrication by CORPs

URBAN MALARIA CONTROL PROGRAM											
ROUTINE ADULT MOSQUITO SURVEILLANCE WITH IFAKARA TENT TRAP (ITT)											
MUNICIPAL (*Manispaa*)											
Ward (*Kata*)											
Name of the volunteer (CORP)											
Date (tarehe)	*Mtaa*	Ten-cell Unit (shina)	House number (Namba ya Nyumba)	Time of entering the tent (muda wa kuingia hemani)	Time of leaving the tent (Muda wa kutoka hemani)	Number of mosquitoes caught (Idadi ya Mbu aliokamata)	Total number of Anopheles (Idadi jumla ya Anophelesi)	Total number of Culex (Idadi jumla ya Culex)	Total number of Aedes (Idadi jumla ya Aedes)	House owner 's name (Jina la mwenye nyumba)	Signature of the house owner (sahihi ya mwenye nyumba)