Published in final edited form as:
Health Policy. 2007 October ; 83(2-3): 196–212.

Comparison of mosquito control programs in seven urban sites in Africa, the Middle East, and the Americas

Daniel E. Impoinvil[a], **Sajjad Ahmad**[*,b], **Adriana Troyo**[a,c], **Joseph Keating**[d], **Andrew K. Githeko**[e], **Charles M Mbogo**[f], **Lydiah Kibe**[f], **John I. Githure**[g], **Adel M. Gad**[h], **Ali N. Hassan**[i], **Laor Orshan**[j], **Alon Warburg**[k], **Olger Calderón-Arguedas**[c], **Victoria M. Sánchez-Loría**[l], **Rosanna Velit-Suarez**[m], **Dave D. Chadee**[n,o], **Robert J. Novak**[p], and **John C. Beier**[a]

a*Global Public Health Program, University of Miami Miller School of Medicine, Miami, FL, USA*

b*Department of Civil and Environmental Engineering, University of Nevada, Las Vegas NV, USA*

c*Centro de Investigación en Enfermedades Tropicales, Departamento de Parasitología, Facultad de Microbiología, Universidad de Costa Rica, San José, Costa Rica*

d*Department of International Heath and Development, Tulane University School of Public Health and Tropical Medicine, New Orleans, LA, USA*

e*Centre for Vector Biology and Control Research, Kenya Medical Research Institute (KEMRI), Kisumu, Kenya*

f*Centre for Geographic Medicine Research-Coast, Kenya Medical Research Institute (KEMRI), Kilifi, Kenya*

g*Human Health Division, International Centre of Insect Physiology and Ecology (ICIPE), Nairobi, Kenya*

h*Research and Training Center on Vectors of Diseases, Ain Shams University, Cairo, Egypt*

i*Institute of Environmental Studies & Research, Ain Shams University, Cairo, Egypt*

j*Laboratory of Entomology, Ministry of Health, Jerusalem, Israel*

k*Department of Parasitology, Kuvin Centre for the Study of Infectious and Tropical Diseases, The Hebrew University -Hadassah Medical School, Jerusalem, Israel*

l*Área Rectora de Salud Puntarenas-Chacarita, Ministerio de Salud, Puntarenas, Costa Rica*

m*Unidad de Desarrollo y Regulación de Servicios de Salud, Ministerio de Salud, Puntarenas, Costa Rica*

n*Insect Vector Control Division, Ministry of Health, St Joseph, Trinidad, West Indies*

o*Department of Life Sciences, University of the West Indies, St Augustine, Trinidad, West Indies*

p*Illinois Natural History Survey, Champaign, IL, USA*

Abstract

*Corresponding Author Email Address: SA: sajjad.ahmad@unlv.edu
Email Addresses:DEI: dimpoinvil@.med.miami.eduAT: atroyo@med.miami.eduJK: jkeating@tulane.eduAKG: AGitheko@kisian.mimcom.netCMM: cmbogo@kilifi.kemri-wellcome.orgLK: lkibe@kilifi.kemri-wellcome.orgJIG: jgithure@icipe.orgAMG: adelgad2002@yahoo.comANH: alihassan_eg@yahoo.comLO: Laor.Orshan@eliav.health.gov.ilAW: warburg@cc.huji.ac.ilOC: olgerc@cariari.ucr.ac.crVMS: vsanchel@ccss.sa.crRV: rosvelit@yahoo.comDDC: Chadee@tstt.net.ttRJN: rjnovak@uiuc.eduJCB: JBeier@med.miami.edu

Mosquito control programs at seven urban sites in Kenya, Egypt, Israel, Costa Rica, and Trinidad are described and compared. Site-specific urban and disease characteristics, organizational diagrams, and strengths, weaknesses, obstacles and threats (SWOT) analysis tools are used to provide a descriptive assessment of each mosquito control program, and provide a comparison of the factors affecting mosquito abatement. The information for SWOT analysis is collected from surveys, focus group discussions, and personal communication. SWOT analysis identified various issues affecting the efficiency and sustainability of mosquito control operations. The main outcome of our work was the description and comparison of mosquito control operations within the context of each study site's biological, social, political, management, and economic conditions. The issues identified in this study ranged from lack of inter-sector collaboration to operational issues of mosquito control efforts. A lack of sustainable funding for mosquito control was a common problem for most sites. Many unique problems were also identified, which included lack of mosquito surveillance, lack of law enforcement, and negative consequences of human behavior. Identifying common virtues and shortcomings of mosquito control operations is useful in identifying "best practices" for mosquito control operations, thus leading to better control of mosquito biting and mosquito-borne disease transmission.

Introduction

Mosquito life cycles and behaviors as well as mosquito-borne pathogen transmission have been the subject of intense research for the past 70 years, yet further study is still needed about the ecology of mosquito population dynamics and control in relation to land use and land change, specifically urbanization [1-5]. It is therefore necessary to assess the biological and non-biological factors influencing mosquito control programs in urban areas to assure they are engaging in appropriate activities that lead to the control of pathogen transmission and a reduction in mosquito populations.

Various types of mosquito control programs operate in different countries. These vary from centralized to decentralized systems, disease system-specific to generalized vector control, government-maintained to community-based control, and specialized to generalized methods of control. Each mosquito control program operates within its own unique political, economic, social, and technological environment. Although, the definition and context of mosquito control programs varies among settings and disciplines, the definition of a mosquito control program used in this study is any program that conducts mosquito control as a tool for the prevention of vector-borne disease and/or for the reduction of nuisance-biting mosquito populations. This definition is based on the understanding that the presence of disease pathogen-transmitting mosquitoes can serve as a serious threat to public health and well being, and many mosquitoes species can cause moderate to severe annoyance and stress to inhabitants that are afflicted [6,7]. This all-encompassing definition of mosquito control program provides a universal concept of the mosquito as a vector, pest or both. Furthermore, the definition of mosquito control activities used in this study is any activity such as killing of mosquito adult and larvae with chemical and biological insecticides, environmental management, mosquito control legislation and mosquito control education that results in reduced mosquito populations. This definition is used because specific mosquito control methods may be more appropriate for different vectors, environments, social settings, and economic conditions [8-10].

Failures of mosquito control programs have been attributed to biological factors like insecticide resistance, as well as to non-biological factors like poor implementation of mosquito control strategies such as failure to translate national goals into district level activities [11], failure to enlist trained entomologists into governmental mosquito control programs [12], and a lack of understanding of social norms and a society's acceptance of mosquito control campaigns [13,14].

In urban areas, several mosquito control challenges exist. Biological challenges such as insecticide resistance and vector behavior are major obstacles in mosquito control [15-18]. Moreover, mosquitoes may be adapting to new environmental conditions and pressures [3], necessitating the need for new mosquito control approaches. Increases in human populations, the breakdown in municipal management, and increased pressure on resources in urban areas can have detrimental effects on a mosquito control program's operational efficacy, and mosquito-prevention public works activities occurring in urban and rural environments [1,8]. Additional challenges of managing mosquito control programs include insufficient funding, weak health infrastructures, limited skilled human capacity, and poor quality private sector services. All of which play a major role in the success or failure of mosquito control operations [19]. The relative importance of these major challenges varies depending on the disease vector, socio-economic conditions of the area, management structure of the program, political will, and other site-specific issues. Despite the aforementioned problems, urban environments typically have better administrative and managerial organization, more elaborate town planning such as demarcations of residential, industrial and commercial zones, more access to municipal resources such as piped water and drainage networks, and more municipal services such as garbage collection and vector/pest control, relative to rural areas. These amenities may provide an opportunity to reduce the mosquito burden in an area, and consequently limit the risk of mosquito-borne disease [5,20].

The World Health Organization (WHO) has called for the acceptance of a global strategic framework for integrated vector management (IVM) [21]. This entails increased emphasis on using all appropriate methods of vector control and inclusion of stakeholders to achieve acceptable levels of disease suppression. Keeping within the spirit of the IVM strategy, we have assembled an interdisciplinary research group, the INTERVECTOR consortium, at the University of Miami in Florida, USA. The term INTERVECTOR is derived from two main themes: "INTER" refers to interdisciplinary, international, and inter-agency, while "VECTOR" refers to insects that transmit pathogens. This group consists of ministry of health officers and a multi-disciplinary group of researchers from: Kenya, Egypt, Israel, Costa Rica, Trinidad and the USA.

Through this international collaboration we have identified seven study sites to conduct the assessment described herein. In this paper we (i) describe and compare mosquito control programs at seven urban sites, (ii) describe and compare the management structure of each program and (iii) assess each program for its strengths, weaknesses, opportunities and threats using the SWOT analysis tool. This study is meant to provide a framework for looking at mosquito control programs in an interdisciplinary manner and bring awareness to the fact that the likelihood of success for a mosquito control program requires integration of information from socially-oriented research in addition to the biologically-based research [22]. The framework provided here does not include outcome factors such as measures of reduced disease and mosquito burden, which would be ideal for evaluating the effectiveness and efficiency in mosquito control activities; however, this study does outline some of the political, economic, social and technical issues facing mosquito control programs. Therefore the goal of this study was not to quantitatively evaluate the abilities of each mosquito control program to reduce pathogen transmission nor reduce mosquito densities. Rather, the goal of the study was to apply a process, often used in business and novel to mosquito control assessment, for the understanding of how mosquito control programs operate across different settings.

2. Methods

2.1. Study sites

The urban sites included in this study are: Malindi and Kisumu, in Kenya; Abu Seir (sub-location in Cairo) and Matar Imbaba (sub-location in Aswan), in Egypt; Herzliya (sub-location of Tel Aviv) in Israel; Puntarenas in Costa Rica; and St. Augustine in Trinidad. Features of the study sites and information on the relevant vector-borne diseases in each are provided in Tables 1 and 2. For example, Table 1 provides an urban profile for city dynamics, population pressure, access to municipal services, and social indicators. Table 2 provides a description of disease systems, and composition of vector species and ecology. These tables are meant to show the heterogeneity in the study sites and provide some level of context for mosquito control activities. These sites were selected because of the perceived risk of specific mosquito-borne disease(s) in these urban sites, and the long standing collaboration with researchers at those sites, who are also members of the INTERVECTOR consortium, and the University of Miami.

2.2. Questionnaires, interviews and SWOT analysis

Questionnaires, interviews, focus-group discussions, and personal communications were used to identify the strength, weaknesses, opportunities, and threats of each mosquito control program. Questionnaires were filled out with the help of government officers actively involved in the mosquito control operations to assess the mosquito control program organization, activities, and the urban characteristics for each study site. Interviews and focus group discussions were used to examine how mosquito control was being conducted in each study site, and to identify some of the challenges faced by each study site. These responses were than used for SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis.

The SWOT analysis is a simple, but robust tool in that it structures information on an organization's internal factors (i.e. resources and capabilities of the organization), and external factors (i.e. circumstances in which it operates) [23]. Through SWOT analysis, organizations can identify their positive and negative attributes and build strategic plans that improve their strengths and minimize their weaknesses.

As a first step for SWOT analysis, the information from the questionnaires, interviews, focus-group discussions, and personal communications were placed into four major macro-environmental themes: 1) Political/Legal, 2) Economic, 3) Social, and 4) Technological. These four themes are conventional categories when doing SWOT analysis [24,25]. For the purpose of this study, these themes were defined as follows: 1) Political/Legal: refers to the political will, bureaucracy, and laws influencing mosquito control operations; Economic: refers to the funding aspect of mosquito control operations; Social: refers to the social interactions and perceptions, and community involvement in mosquito control operations; and Technological: refers to all biological and technical aspects of mosquito control operations such as mosquito behavior and ecology, geographical environment and operations. The four themes are relevant to our sites as they capture the major factors (i.e. biological, social, economic and political factors) affecting mosquito control in each setting. By developing a framework that highlights these factors using standard and universally accepted themes, SWOT analysis can be comparable across different study sites [24-26], although we recognize that the relative importance of the various SWOT variables may differ across countries as a function of cultural and political context.

As a second step for SWOT analysis, the information obtained was categorized as a strength, weakness, opportunity or threat for the program. Factors that are desirable practices in mosquito control operations, and are under the direct handling of the mosquito control program were considered strengths. Factors that are non-desirable practices in mosquito control operations and are under the direct handling of the mosquito control program were considered weaknesses. Factors that have the potential to benefit mosquito control operations, but are not under the direct handling of the mosquito control program were considered opportunities. Factors that have the potential to hinder mosquito control operations, but are not under the direct handling of the mosquito control program, were considered threats.

2.3 Ranking of decision-making factors

Ministry of health officers in each of our study sites were asked to grade the following factors: disease epidemiology, vector control resources (i.e. equipment and materials necessary to do specific control activities), financial resources (i.e. monies to fund control activities), technical expertise, manpower/labor, social/community considerations, business/commercial incentives, and government willingness as either major or minor factors, or not considered when making decisions regarding mosquito control. Ministry of Health officers were further asked to identify and rank the top 3 factors influencing mosquito control decision-making regarding mosquito control.

2.4 Comparison of mosquito control programs

A comparison of mosquito control programs was done to determine whether each mosquito control program had standard components of a mosquito control program, as suggested by Hatch et al. (1973) and Challet (1994) [27, 28]. Responses from questionnaires, interviews focus-group discussions and personal communications were used to determine whether each mosquito control program had the following components:

1. Legislation - laws which function to deter mosquito proliferation
2. Entomological Surveillance - monitoring of mosquito population
3. Epidemiological Surveillance - monitoring of mosquito-borne disease
4. Environmental Management - utilization of environmentally-safe physical methods that modify or manipulate the environment to make it less conducive for mosquitoes to interact with man
5. Biological Control - safe (to both the human and environment) utilization of bio-control agents that kill adult or larval mosquitoes
6. Chemical Control - safe (to both the human and environment) utilization of chemical control agents that kill adult or larval mosquitoes
7. Public Education - implementation of campaigns that inform people on how mosquito-borne pathogens are transmitted and how they can be avoided
8. Activity Reports - routine records on mosquito control activities
9. Training/Continuing Education - training and information on topics related to mosquito-borne disease and its control
10. Inter-Sector Collaboration - joint mosquito and disease control ventures between government institutions, international organizations, non-governmental organizations (NGOs), and community stakeholders
11. Applied Local Research - continuous investigation of the biology and distribution of the local mosquito population and research into control methods that are appropriate for the local environment.

The responses were compiled and reported in matrix form. We did not verify the utilization of these components for mosquito control efforts, nor was it possible to verify objectivity of the responses through a record review. However, the people who were interviewed work closely with mosquito control activities, and provided us with a description of mosquito control operations based on their years of experience and knowledge.

3. Results

3.1. Organizational diagram

The mosquito control programs assessed had unique organizational approaches for the control of mosquitoes (Figure 1a-1f). Aswan, Cairo and St. Augustine have centralized mosquito control programs, with a vertical organization of ministries down to the municipal level. Kisumu and Malindi, Kenya, Herzliya, and Puntarenas have decentralized mosquito control programs, with a horizontal organization of the municipality or other local institutions and the government ministries.

Based on the organizational diagrams, all study sites appear to have some sort of inter-sector collaboration or joint ventures with other institutions, with the exception of Kisumu. The diagram of the Puntarenas mosquito control program shows a number of partners formally involved in mosquito control suggesting a high level of inter-sector collaboration. Costa Rica has recently implemented a novel and more elaborate approach to mosquito control compared to their previous method of control that consisted of a centralized system of mosquito control, primarily for malaria prevention. The strategy that is currently being used in Costa Rica uses epidemiological stratification of the local site-specific situation to address the specific needs of the site. In Costa Rica, dengue is now being viewed as a societal problem that requires inter-sector collaboration from the national and local government organizations, the community and private stakeholders to reduce dengue transmission. Formal environmental health components, in the form of Ministries, units, divisions, and sanitation services were present in all organizational diagrams, with the exception of Puntarenas. However, environmental activities were included as part of the general work processes in Puntarenas. Involvement of other Ministries, governmental offices, academic institutions, community institutions and groups in mosquito control operations, varied in the different study sites. The organizational diagram for Malindi and Herzliya shows that the civil engineering departments were part of mosquito control operations. Participation of engineering in the other programs was not evident by the diagrams. The ministry of agriculture and ministry of water and irrigation were also involved in mosquito control efforts in Aswan and Cairo. All but two of the organization diagrams (Herzliya and Trinidad) revealed the presence of community participation in mosquito control operations. Community participation was typically at the final (bottom) level of mosquito control operations suggesting that decisions-making was done at the government level down to the community level. Community participation for mosquito control activities varied at different study sites. In Kisumu, community activities for mosquito control consist of education on mosquito control through the training of trainers (ToTs) program (educating community groups and have them educate the greater community) and distribution of insecticide-treated nets (ITNs). In Malindi, community activities for mosquito control consist of small-scale draining and filling of water bodies with mosquito larvae, income generation activities such as manufacturing of bed nets to be sold to hotels, and education of residents on mosquito control through the ToT program. In Egypt, activities are currently underway to develop a training of trainers (ToT) program. In Puntarenas, the Association of Community Networks participates in mosquito control activities by joining the education campaign for source reduction activities.

3.2. Ranking of decision-making factors

The seven study sites varied slightly in what managers considered as major and minor factors driving decision-making in mosquito control operations (Table 3). In all study sites disease epidemiology, vector control resources, and government willingness were all considered as major factors in the decision making process of mosquito control operations. Financial resources were also a major factor in the decision making process in all sites except St. Augustine, Trinidad, where it was considered a minor factor. Business and/or commercial incentives were considered minor factors influencing mosquito control in Malindi and Herzliya, but in the other study locations they were not considered.

Of the top three factors considered when making decisions for mosquito control activities, disease epidemiology was the number one factor for all study sites. Five (Kisumu, Malindi, Abu Seir, Matar Imbaba, and Herzliya) of the seven study sites identified vector control resources as one of the top three factors considered when making decisions for mosquito control activities; making it the second most commonly mentioned factor. Vector control resources were ranked second in Kisumu, Malindi, and Herzliya and ranked third in Abu Seir and Mata Imbaba. Three (Abu Seir, Matar Imbaba, and St. Augustine) of the seven study sites identified government willingness as one of the top three factors considered when making decisions for mosquito control activities, with all three sites ranking it as the second most important factor.

3.3. SWOT Analysis

The results of the SWOT analysis are summarized in Table 4. Though, the results for SWOT were similar at sites within Kenya and Egypt, there were differences reported. For example, in Malindi it was mentioned that competing activities from the national government causes redundancy in projects and undermines the efforts of the local government, while in Kisumu it was reported that funding was provided by several different Ministries to help support mosquito control efforts. Common to these seven mosquito control programs is the concern of funding for their mosquito control efforts. Generally, this was a threat for all mosquito control programs. In Trinidad however, this seemed to be less of a problem, since considerable funding was available for mosquito control efforts; it was also reported that the funding received for mosquito control was influenced by the political climate. Conversely, the Israeli government was increasing monies for mosquito control to combat West Nile Virus, which would benefit Herzliya. However, with increasing threat from other disease outbreaks such as SARS and avian flu, this funding may be limited. In Kenya, issues of corruption and an informal sector that does not pay taxes was reported as a major problem for mosquito control.

3.4. Cross comparison

Table 5 shows a cross comparison of techniques used to control mosquitoes in each study site. Herzliya and St. Augustine were the only study sites that reported the use of all techniques to control mosquitoes, which would suggest that these programs are robust in their mosquito control operations. The components listed in Table 5 are meant to serve as guidelines for mosquito control, and are not a standard method of organization [27,28]. This is important because not all components may be appropriate or feasible for a mosquito control program to achieve success in reducing pathogen transmission or mosquito abundance. However, by having these components in place, it is likely that mosquito control activities will be enhanced. [19,27-29].

4. Discussion

In this study we describe and compare mosquito control programs in urban areas identified as part of our INTERVECTOR projects. We outline the mosquito control organizational structure used in each urban area; provide a context of mosquito control in terms of disease heterogeneity; assign relative importance to decision making factors; and use SWOT analysis to identify strengths, weaknesses, opportunities and threats of the respective mosquito control programs.

As expected, the organizational structure of mosquito control programs varied between urban areas. The utilization of different organizational structures in mosquito control programs is influenced by a myriad of factors including, the biological disease systems, political will (or government willingness), economic development, social relationships, and cultural norms. The organizational structure showed the institutional participants in each mosquito control program, and where each entity is positioned in the grand scheme of mosquito control. For example, in the organizational diagrams of St. Augustine and Puntarenas, the University of the West Indies and the University of Costa Rica were included, suggesting that they are recognized as contributing members of mosquito control activities (Figure 1e and 1f). Knowledge of the organizational structure of mosquito control programs and the participants involved in a mosquito control program may help to explain why various decisions are being or not being made for mosquito control. For example, the lack of participation of civil engineers in mosquito control programs would make it less likely that mosquito control activities related to engineering such as construction of functional drainage systems for the prevention of mosquito proliferation is occurring. Awareness of the organization structure of mosquito control programs and its participants may provide underlying reasons of how mosquito control operate in a country, and how it can potentially be improved upon through integration of other relevant Ministries, institutions, organizations or groups.

In Table 3 we provide a ranking of factors considered when making decisions regarding mosquito control activities. Understanding decision-making processes, and the relative importance assigned to factors that influence mosquito control programs, is important because decision-makers can make their decision based on intuition, empirical evidence, or on other considerations that include crises, current public opinion, political interests, or the concerns of organized interest groups [30]. The lack of evidence-based decision making can be a major obstacle to effective mosquito control. Decisions that are made without the consideration of the epidemiological and biological situation may lead to neutral outcomes such as no impact on disease transmission or no reduction in mosquito-vector populations. In Malindi, it was reported that entomological surveillance for their mosquito control program was not conducted (Table 4); this may suggest that factors other than entomological surveillance, are utilized to make decisions for mosquito control.

This study has the potential to inform decision-makers and guide mosquito control policy. Matching of Strengths, Weaknesses, Opportunities and Threats together may provide strategic approaches to managing mosquito control. In Malindi for example, mosquito control is considered a major public health priority because of the positive effects it has on the economy through tourism; this was viewed as an opportunity for mosquito control (Table 4). Alternatively, Malindi lacks adequate funding to engage in good mosquito control; this was a weakness of mosquito control. By matching this opportunity with this weakness, Malindi should consider implementation of a tourist’s tax devoted for mosquito control operations (Table 4). To increase inter-sector collaboration, the Ministry of Tourism could be involved in mosquito control programs.

In Cairo and Aswan, SWOT analysis revealed the opportunity that the universities in Egypt have done elaborate studies related to mosquito biology and control; however, they are not included in the organization diagram of mosquito control organization (Table 4). In Egypt, it was suggested that mosquito control operations may not be based on scientific data and information about the target species (Table 4). By incorporating results of scientific research from academic institutions, Ministries can inform the implementation of sound interventions that best affect the biological specificities of the targeted vector. The Egyptian government should consider involving Egyptian universities in a more active role in general mosquito control operations. This would allow the academic study of vectors to have practical implications, thus bridging a gap between research and field implementation of mosquito control.

The government officers involved in the mosquito control programs at different study sites reported that they do have many of the essential components for mosquito control as suggested by Hatch et al. (1973) and Challet (1991, 1994) (Table 5). However, they also reported having problems with pathogen transmission and the nuisance associated with biting mosquitoes in their environments. We speculate that though these government officers may report that they have the various components in place to control mosquito vectors, it is possible that these strategies are either 1) not being used efficiently, 2) not being properly integrated in a manner that leads to reduced pathogen transmission and nuisance-mosquito burden, or 3) insufficient to control mosquitoes and disease and require a different conceptual approach. What ever the case, we conclude that increased evaluation of the mosquito control programs is mandatory to identify the weaknesses and strengths of mosquito control programs to manage pathogen transmission and mosquito population.

Heavy emphasis on the study of the biology of mosquito-borne disease and development of novel control methods has overshadowed the study of management of mosquito control operations in developing countries. Barat et al (2006) reviewed four malaria control programs that were successful in reducing malaria burden [19]. The common success factors that were identified included, conducive country conditions, a targeted technical approach using a package of effective tools, data-driven decision-making, active leadership at all levels of government, involvement of communities, decentralized implementation and control of finances, skilled technical and managerial capacity at national and sub-national levels, hands-on technical and programmatic support from partner agencies, and sufficient and flexible financing [19]. These factors may be useful for the sites we studied, in particular data-driven decision making.

Understanding local variability in mosquito control programs is needed. However, mosquito control approaches applied in one study site may also be effective in another study site in some situations [31]. The importance of this is that each of our INTERVECTOR study sites could potentially adopt strategies that are used by other sites to address similar issues. For example, in Malindi managers of hotel businesses are being approached to support community-based mosquito control efforts. These managers are being persuaded to assist in these efforts because less vector-borne disease and less nuisance biting from mosquitoes could lead to increased benefit for their businesses. Each study site could essentially do the same by appealing to the dominant business in the area.

In a historical review of malaria control, Najera stated, “The definition not only of the control approaches but also of their conditions of applicability will become more precise as experiences are accumulated and adequately documented from different types of epidemiological situations.” [31]. Therefore the need for interdisciplinary studies of mosquito control program using techniques such as SWOT analyses is important, not only for complementing biological, epidemiological and ecological studies, but also facilitating them.

5. Conclusion

In this study, using Site-specific urban and disease characteristics, organizational diagrams, and SWOT analysis tools, we describe and compare mosquito control programs at seven urban sites in Kenya, Egypt, Israel, Costa Rica, and Trinidad. Discovery that the organizational structure of each mosquito control program was heterogeneous at each study sites was not surprising, in that each mosquito control program is attempting to address different issues in regards to disease(s) and mosquitoes. Additionally, the varied geographical settings, socio-economic character, and political and cultural contexts also can contribute to the heterogeneous organization of mosquito control programs. By comparatively looking at the organizational diagrams of different study sites, major and supporting entities of the programs were observed.

For example, Kisumu and Malindi seem to rely heavily on the community organization to assist in delivering mosquito and disease control to the broader community. Further, understanding the factors that influence mosquito control decision-making lend insight into how decision makers view mosquito control. In this study, several factors were ranked as major factors in decision-making for control such as vector control resources and government willingness; however, the number one major factor for all study sites in mosquito control decision-making was disease epidemiology. The fact that disease epidemiology was recognized as a key component in decision-making in mosquito control suggests that the evidence-based decision-making may be occurring at the study sites; however, the extent to which this is being done effectively and efficiently is not known. Proper use of evidence-based decision-making will reduce the decisions being made on external factors, which may have lower relevance for mosquito control.

Outlining and comparing some of the merits and deficiencies of mosquito control programs through analyses such as SWOT provides a framework to develop novel mosquito control programs that contain necessary features for effective and efficient mosquito control operations. Similarly, by matching various factors of successful mosquito control programs, better approaches to mosquito control can be developed. For example, in Malindi, by matching the mainstay industry of tourism with the threat of deficient funding for mosquito control, possibly a tourist tax may be imposed that would fund mosquito control operations. By developing a comprehensive understanding of the various factors involved in mosquito control, strategies can be developed that are not only sensitive to political, economic, social, and technical aspects of the urban environment, but also responsive to the burden caused by mosquitoes and mosquito-borne disease.

Several methods of mosquito control are in place in different countries for different reasons, and beyond biological rationale there is only intuitive reasoning for why various countries adopt the system of operations they do for mosquito control. By comparing mosquito control programs, as done in this study, common and unique themes can be identified and plans can be put in place to improve the operational efficacy and efficiency of mosquito control programs.

Acknowledgements

We thank Tina Collazo for administrative and technical assistance, and members of our INTERVECTOR research team at the University of Miami for their comments and suggestions on this project. This study was supported by the National Institute of Health grant number, P20 RR020770.

References

[1]. Knudsen AB, Slooff R. Vector-borne disease problems in rapid urbanization: new approaches to vector control. Bulletin of the World Health Organization 1992;70:1–6. [PubMed: 1568273]

[2]. Lines J, Harpham T, Leake C, Schofield C. Trends, priorities and policy directions in the control of vector-borne diseases in urban environments. Health Policy and Planning 1994;9:113–29. [PubMed: 15726774]

[3]. Patz JA, Graczyk TK, Geller N, Vittor AY. Effects of environmental change on emerging parasitic diseases. International Journal for Parasitology 2000;30:1395–405. [PubMed: 11113264]

[4]. Patz JA, Daszak P, Tabor GM, Aguirre AA, Pearl M, Epstein J, Wolfe ND, Kilpatrick AM, Foufopoulos J, Molyneux D, et al. Unhealthy landscapes: Policy recommendations on land use change and infectious disease emergence. Environmental Health Perspectives 2004;112:1092–8. [PubMed: 15238283]

[5]. Robert V, Macintyre K, Keating J, Trape JF, Duchemin JB, Warren M, Beier JC. Malaria transmission in urban sub-Saharan Africa. American Journal of Tropical Medicine and Hygiene 2003;68:169–76. [PubMed: 12641407]

[6]. National Research Council. Urban pest management: a report. National Academy Press; Washington, DC: 1980.

[7]. Service, MW. Medical Entomology for Students. Chapman and Hall; London: 1996.

[8]. WHO. Integrated vector control. Seventh report of the WHO Expert Committee on Vector Biology and Control. World Health Organization Technical Report Series 1983;688:1–72. [PubMed: 6414188]

[9]. Mitchell, CJ. Environmental management for vector control. In: Beaty, BJ.; Marquardt, WC., editors. The Biology of Disease Vectors. University Press of Colorado; Niwott, Colorado: 1996.

[10]. WHO. Environmental management for vector control. Third report of the WHO Expert Committee on Vector Biology and Control. World Health Organization Technical Report Series 1980;649:1–75. [PubMed: 6775421]

[11]. Alilio MS, Kitua A, Njunwa K, Medina M, Ronn AM, Mhina J, Msuya F, Mahundi J, Depinay JM, Whyte S, et al. Malaria control at the district level in Africa: the case of the muheza district in northeastern Tanzania. American Journal of Tropical Medicine and Hygiene 2004;71:205–13. [PubMed: 15331839]

[12]. Gratz NG. Education and employment of medical entomologists in *Aedes aegypti* control programmes. Gaoxiong Yi Xue Ke Xue Za Zhi 1994;10(Suppl):S19–27. [PubMed: 7844845]

[13]. Suarez MR, Olarte SM, Ana MF, Gonzalez UC. Is what I have just a cold or is it dengue? Addressing the gap between the politics of dengue control and daily life in Villavicencio-Colombia. Social Science and Medicine 2005;61:495–502. [PubMed: 15893062]

[14]. Whiteford LM. The ethnoecology of dengue fever. Medical Anthropology Quarterly 1997;11:202–23. [PubMed: 9186961]

[15]. Roberts DR, Andre RG. Insecticide resistance issues in vector-borne disease control. American Journal of Tropical Medicine and Hygiene 1994;50:21–34. [PubMed: 8024082]

[16]. Crampton JM. Approaches to vector control: new and trusted. Prospects for genetic manipulation of insect vectors. Transactions of the Royal Society of Tropical Medicine and Hygiene 1994;88:141–3. [PubMed: 8036652]

[17]. Curtis CF. An overview of mosquito biology, behaviour and importance. Ciba Foundation Symposium 1996;200:3–7. [PubMed: 8894286]

[18]. Pates H, Curtis C. Mosquito behavior and vector control. Annual Review of Entomology 2005;50:53–70.

[19]. Barat LM. Four malaria success stories: how malaria burden was successfully reduced in Brazil, Eritrea, India, and Vietnam. American Journal of Tropical Medicine and Hygiene 2006;74:12–6. [PubMed: 16407339]

[20]. WHO. Financial implications for integration of vector control activities in primary health care. World Health Organization; Geneva: 1986. p. 1-6.

[21]. WHO. Global strategic framework for integrated vector management. World Health Organization; Geneva: 2004. p. 1-15.

[22]. Mwenesi HA. Social science research in malaria prevention, management and control in the last two decades: an overview. Acta Tropica 2005;95:292–7. [PubMed: 16011829]

[23]. Kaufman, R.; Oakley-Browne, H.; Watkins, R.; Leigh, D. Strategic planning for success: Aligning, people, performance, and payoffs. John Wiley & Sons, Inc; San Francisco: 2003.

[24]. Genus, A. Flexible strategic management. Chapman and Hall; London: 1995.

[25]. Hannagan, T. Mastering strategic management. Palgrave; New York: 2002.

[26]. Johnson, G.; Scholes, K. Exploring strategic management. Prentice Hall; Scarborough, Ontario: 1989.

[27]. Hatch CL, Williams JW, Jarinko PA. Guidelines for measuring proficiency as an aid in mosquito abatement program assessment. Mosquito News 1973;33:228–233.

[28]. Challet GL. Mosquito abatement district programs in the United States. Gaoxiong Yi Xue Ke Xue Za Zhi 1994;10(Suppl):S67–73. [PubMed: 7844853]

[29]. Challet GL. Elements of a vector control program. Journal of the American Mosquito Control Association 1991;7:103–6. [PubMed: 2045798]

[30]. Pappaioanou M, Malison M, Wilkins K, Otto B, Goodman RA, Churchill RE, White M, Thacker SB. Strengthening capacity in developing countries for evidence-based public health: the data for decision-making project. Social Science and Medicine 2003;57:1925–37. [PubMed: 14499516]

[31]. Najera JA. Malaria control: present situation and need for historical research. Parassitologia 1990;32:215–29. [PubMed: 1983429]

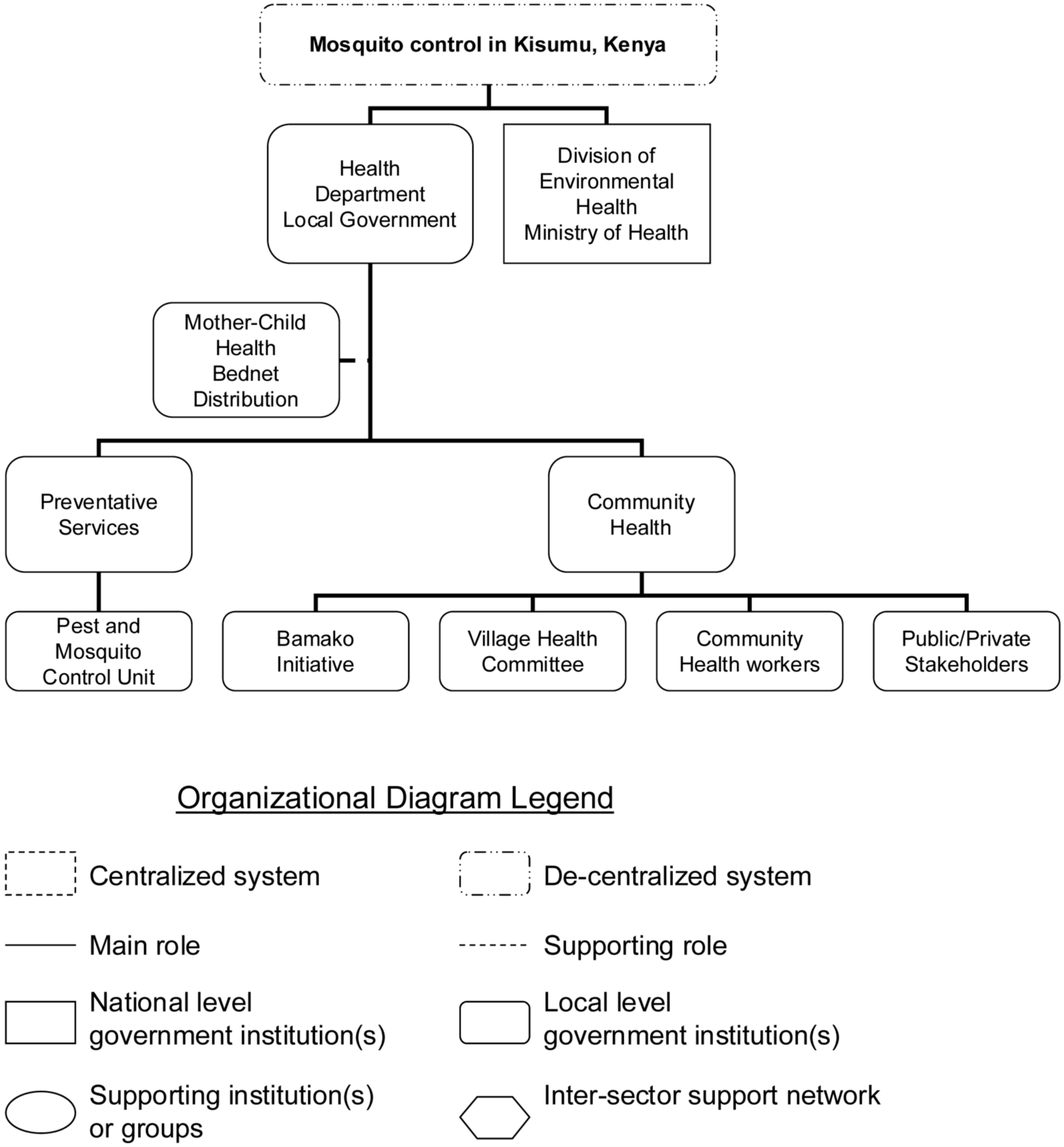


Figure - 1a.
Organizational diagram for mosquito control operations in Kisumu, Kenya

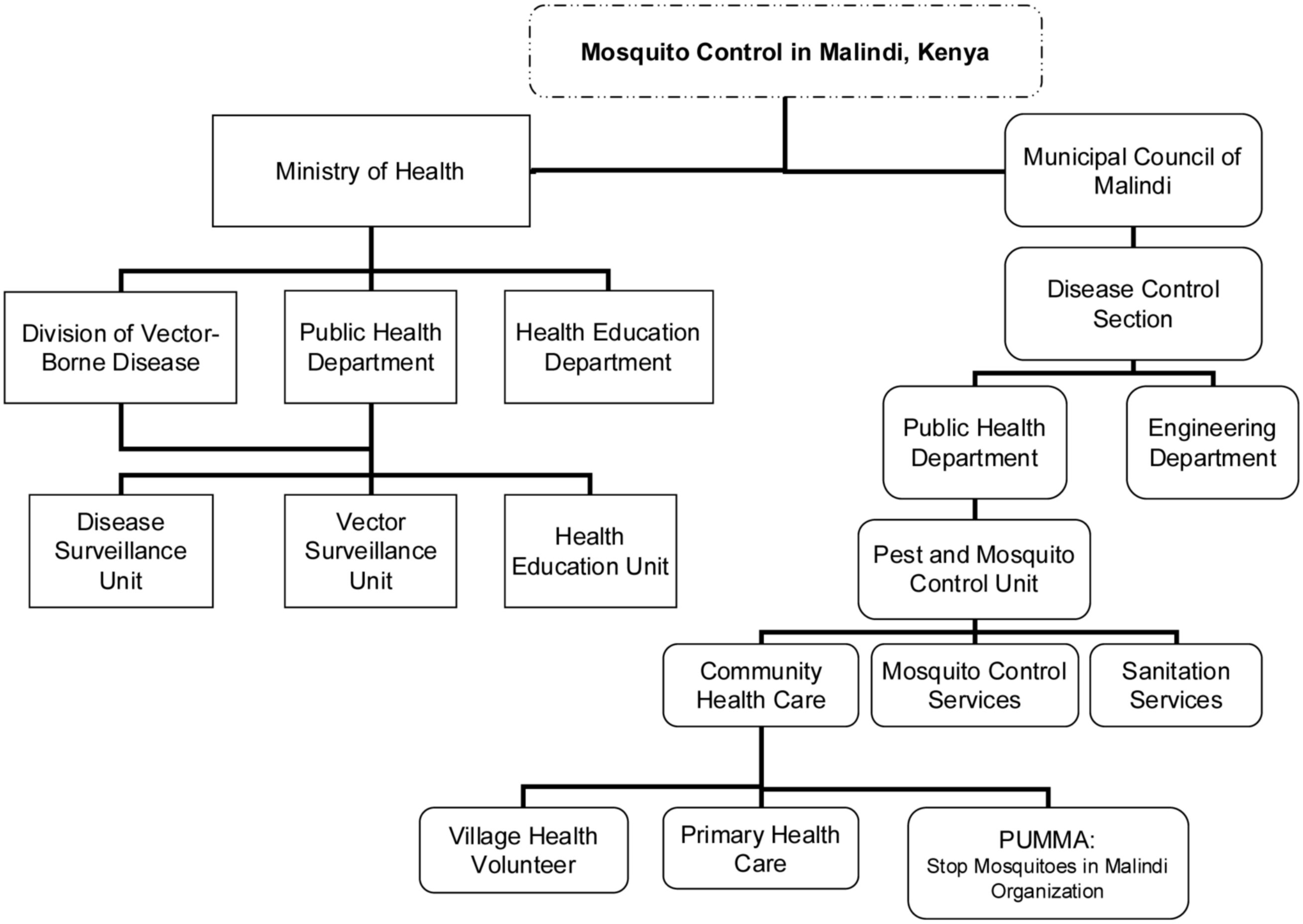


Figure - 1b.
Organizational diagram for mosquito control operations in Malinid, Kenya

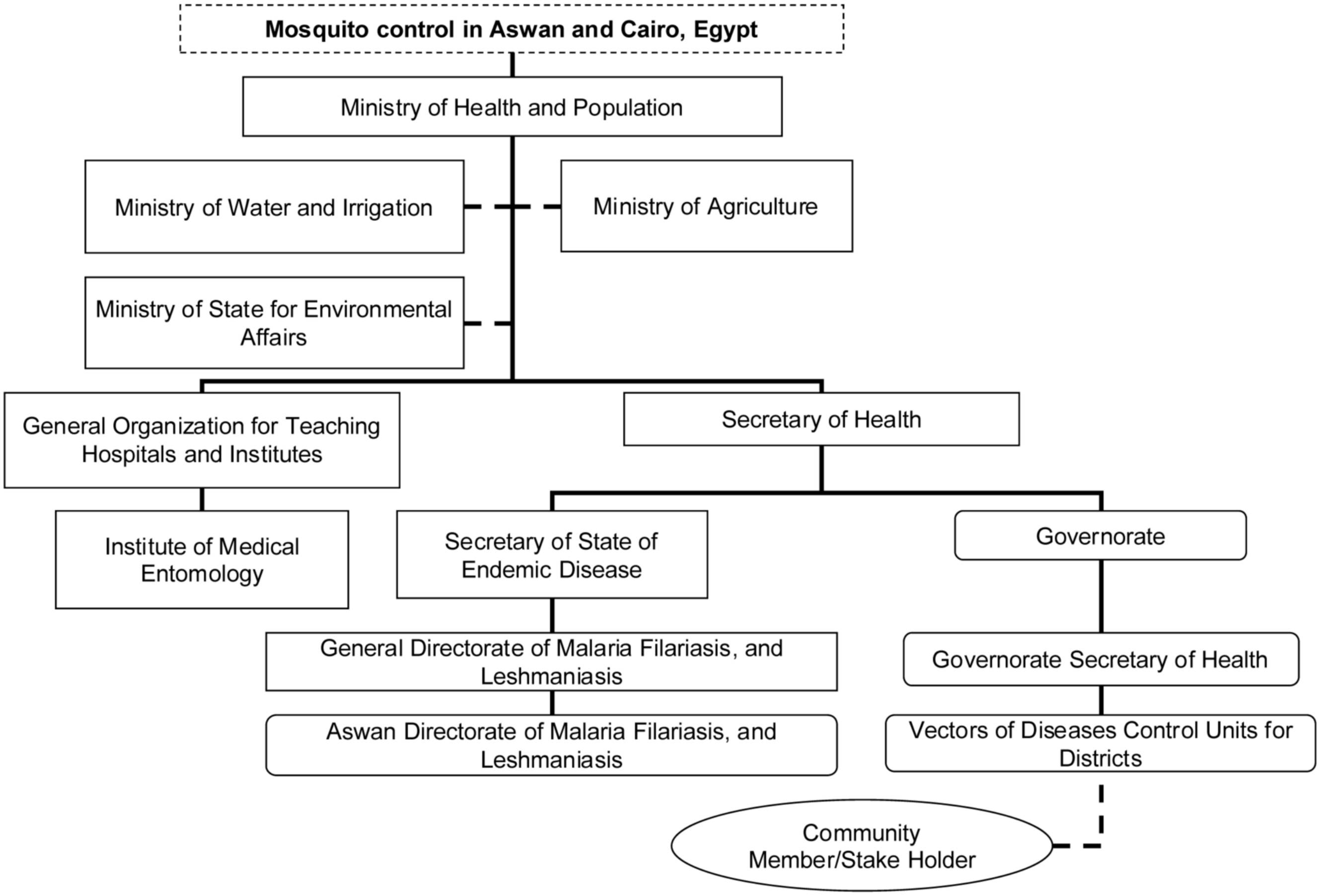


Figure - 1c.
Organizational diagram for mosquito control operations in Aswan and Cairo, Egypt

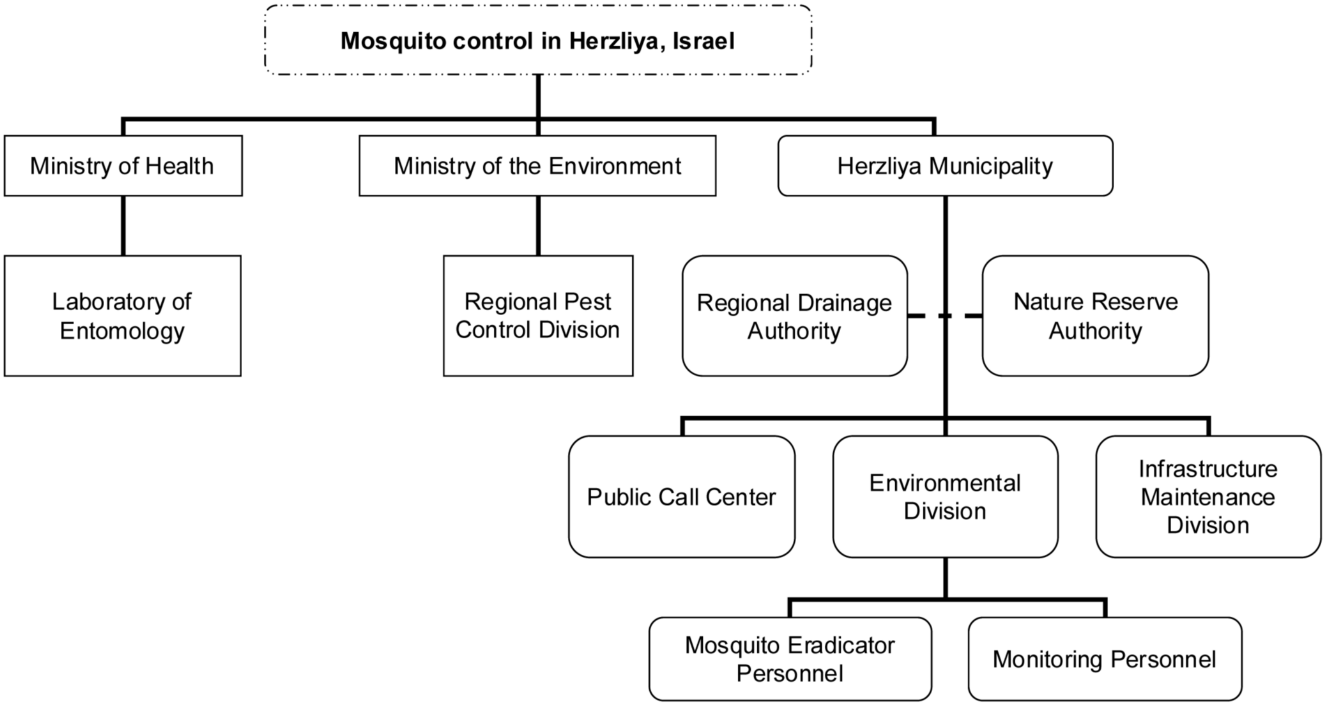
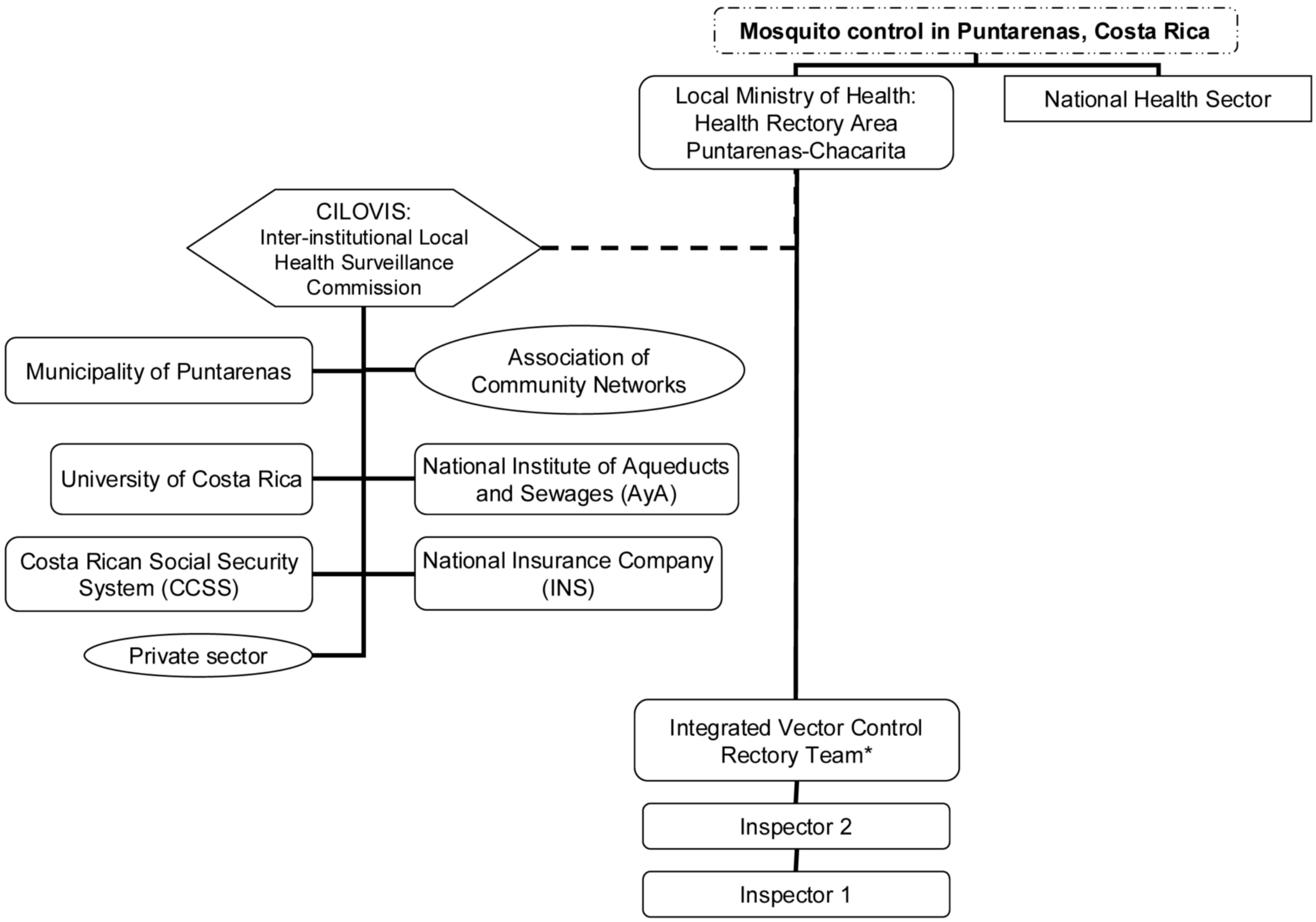


Figure - 1d.
Organizational diagram for mosquito control operations in Herzliya, Israel



* Work Processes: Health Surveillance, Health Promotion, Protection of Human Environment, Regulation, Direction and Strategic Planning, Integrated Vector Control

Figure - 1e.
Organizational diagram for mosquito control operations in Puntarenas, Costa Rica

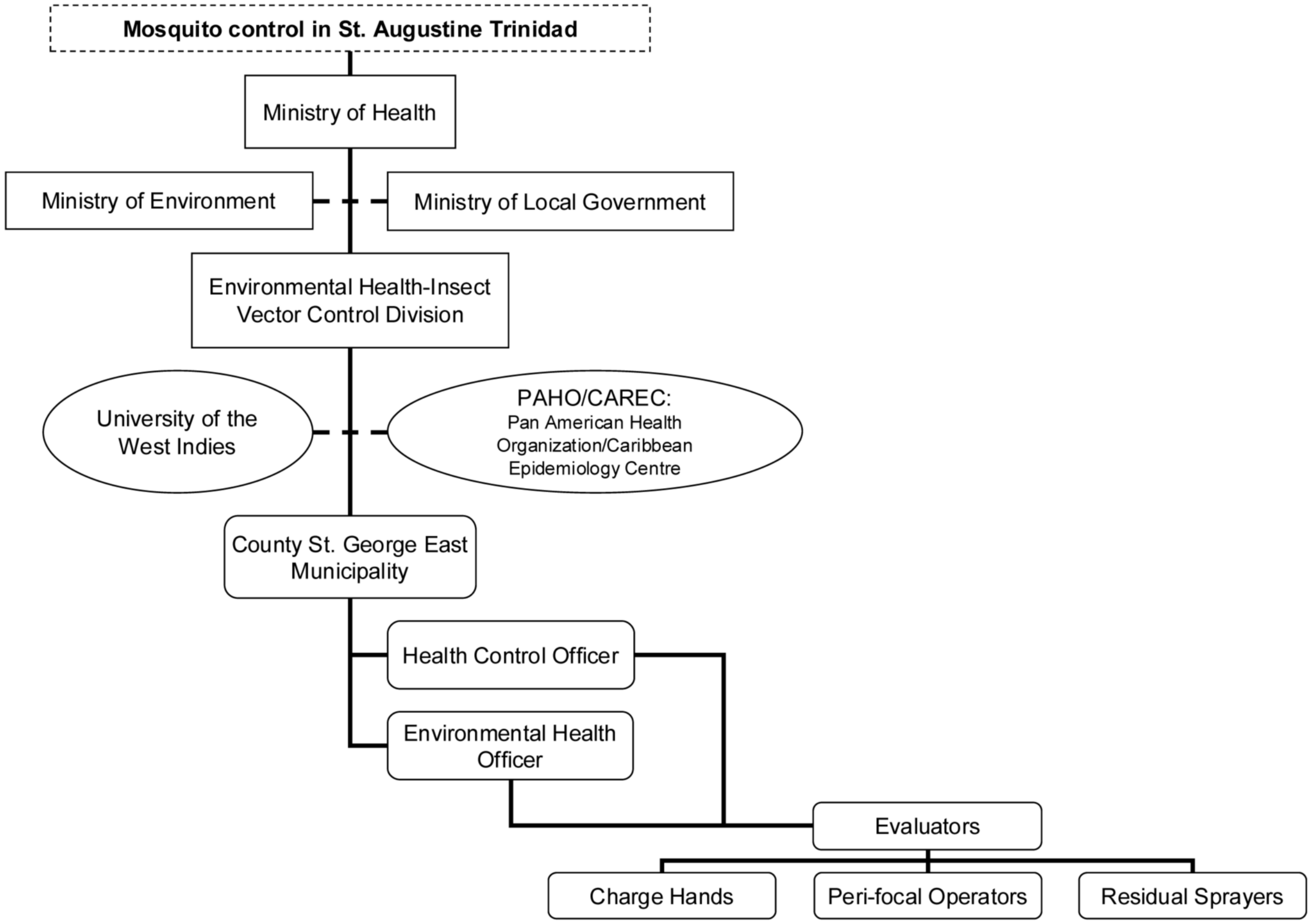


Figure - 1f.
Organizational diagram for mosquito control operations in St. Augustine, Trinidad

Table 1

Urban profile of study sites

y site urban characteristics†	Study site						
	Kisumu, Kenya	**Malindi, Kenya**	**Abu Seir, Egypt**	**Matar Imbaba, Egypt**	**Herzliya, Israel**	**Puntarenas, Costa Rica**	**St. Augustine, Trinidad**
n classification*	Major city	Town	Peri-urban extension town‡	Peri-urban extension town‡	Town	Minor city	Town
iption of major urban activity	Trade city	Tourist town	Commercial/ residential town	Commercial/ residential town	Commercial/ residential town	Port city	University town
ation (people)	600,000	80,591	498,110	40,946	86,000	43,000	15,000
umber in study site	110,000	19,461	115,017	9,705	28,000	12,000	5,000
ze (people/house)	5	4	4	4	3	4	3
site size (km^2)	32	36	ND	ND	26	48	246
ation density (people/km^2)	6,375	2,239	ND	ND	3,308	896	61
ith electricity (%)	25.0	50.0	99.7	98.5	100	99.0	100.0
ith sewers (%)	15.0	10.0	98.4	94.6	100	80.0	100.0
ith piped water (%)	30.0	20.0	85.3	95.4	100	99.0	100.0
s paved (%)	40.0	25.0	70	ND	100	60.0	99.0
literacy rate (%)	35.0	81.0	ND	ND	97.0	90.3	85.0
ation below poverty line (%)	42.0	26.5	ND	ND	ND	ND	30.0

H=households, ND = no available data

ographic information are presented as estimates provided by Ministry of Health offers.

n classification was based on major economic activities, population, and definition of urban provided by municipal officers.

-urban extension town refers to small surrounding towns outside the main urban center of Cairo and Aswan.

Table 2

Description of major vector-borne disease systems and vector composition for each study locale

Disease Pathogen	Reservoir/ amplifying host	Natural Ecology[b]	Epidemiological manifestation	Study site	Vector(s)
Protozoan disease					
Malaria	Human	R,S	Endemic	Kisumu, Kenya	*Anopheles gambiae ss, An. arabiensis, An. funestus*
			Endemic/Epidemic?**	Malindi, Kenya	*An. gambiae ss, An. arabiensis, An. merus*
			Epidemic	Abu Seir and Matar Imbaba, Egypt*	*An. pharoensis, An. sergenti*
Arboviral diseases					
Dengue	Human, primate***	U,S,R	Epidemic	Malindi, Kenya	*Aedes aegypti*
			Epidemic	Puntarenas, Costa Rica	*Ae. aegypti*
			Epidemic	St. Augustine, Trinidad	*Ae. aegypti*
West Nile Virus	Birds	R,S,U	Epidemic	Abu Seir and Matar Imbaba, Egypt	*Culex pipiens, Cx. antennatus, Cx. perexiguus*
			Epidemic	Herzliya, Israel	*Cx. pipiens, Cx. perexiguus*
Rift Valley Fever	Ruminants (e.g. cattle)	R	Epidemic	Abu Seir and Matar Imbaba, Egypt	*Cx. pipiens, Cx. antennatus Ocherlotatus caspius*

[a] Though other mosquito-borne disease are also present in each respective study site only those mentioned in this table will be given consideration

[b] U = urban, S = suburban; R = rural; the underline designates the most important ecology

* Malaria has been found recently in Cairo, and Aswan is at risk for malaria outbreaks

** In Malindi there is very low transmission of malaria so it no clear whether malaria is truly endemic or epidemic

*** Primates are not a significant part of dengue transmission in Trinidad, Costa Rica nor Malindi, but they can be part of transmission in other areas.

Table 3

Importance of factors considered when making decisions for mosquito control activities in study sites

Factors	Study sites						
	Kisumu	**Malindi**	**Abu Seir**	**Matar Imbaba**	**Herzliya**	**Puntarenas**	**St. Augustine**
Disease epidemiology	Major[1]	Major[1]	Major[1]	Major[1]	Major[1]	Major[1]	Major[1]
Vector control resources	Major[2]	Major[2]	Major[3]	Major[3]	Major[2]	Major	Major
Financial resources	Major[3]	Major	Major	Major	Major	Major[2]	Minor
Technical expertise	Minor	Major[3]	Major	Major	Minor	Minor	Major
Manpower/Labor	Minor	Major	Major	Major	Minor	Major[3]	Major[3]
Social/community considerations	Minor	Major	Minor	Major	Major[3]	Major	Major
Business/commercial incentives	Not considered	Minor	Not considered	Not considered	Minor	Not considered	Not considered
Government willingness	Major	Major	Major[2]	Major[2]	Major	Major	Major[2]

Subscript denote the top 3 factors driving mosquito control activities

Table 4

Cross tabulation of SWOT analysis of all the current mosquito control programs

	Internal factors				External factors			
Study site	**STRENGTHS (Desirable practices)**		**WEAKNESSES (Non-desirable practices)**		**OPPORTUNITIES (Benefits to performance)**		**THREATS (Obstacles to performance)**	
Kisumu	• Presence of mosquito control laws	P	• Low community involvement	S	• Government perception of mosquito control as a major public health priority	P	• Corruption in Kenya prevents enforcement of laws	P
	• Inter-sector funding	E			• Availability of international funds for malaria control	E	• Large percentage of population employed by informal sector; Low tax collection	E
	• Plans for guided community-based mosquito control	S			• Presence of existing community-based programs-Bamako Initiative	S	• Human behavioral practices may increase mosquito burden	S
	• Strategic planning for integrated mosquito control	T			• Synergy of mosquito control may be feasible	T		
Malindi	• Presence of mosquito control laws	P	• Competing activities at national and local level	P	• Government perception of mosquito control as a major public health priority	P	• Corruption in Kenya prevents enforcement of laws	P
	• Plans for guided community-based mosquito control	S	• Lack of funding	E	• Local government desires to boost tourism	E	• Large percentage of population employed by informal sector; Low tax collection	E
	• Strategic planning for integrated mosquito control	T	• Lack of good integrated mosquito control	T	• Availability of international funds for malaria control	S	• Human behavioral practices may increase mosquito burden	S
					• Presence of existing community-based programs-Green Town Movement	T	• Topography may be a factor, which allow mosquitoes to propagate	T
					• Synergy of mosquito control may be feasible	T		
Aswan	• Strategic planning for integrated mosquito control	T	• Poor awareness of the people	S	• High level of access to municipal services	T	• Government perception mosquito control as a minor public health priority	P
					• Egyptian Universities has conducted elaborate entomological research	T	• Low sanitation index	S
							• Resource development projects may increase disease transmission	S
							• Human migration poses risk for increased disease transmission	S
							• Poor understanding of mosquito-borne disease transmission in Egypt	S
							• Mosquito control operations not based on scientific information and data of target vector	T
Cairo	• Strategic planning for integrated mosquito control	T	• Restricted access to military sites where mosquitoes are known to be breeding	P	• Better mosquito control organization in capital city	P	• Government perceptions that reports of disease will affect tourism	P

	Internal factors				External factors			
Study site	STRENGTHS (Desirable practices)		WEAKNESSES (Non-desirable practices)		OPPORTUNITIES (Benefits to performance)		THREATS (Obstacles to performance)	
			• Utilization of poor mosquito control methods	T	• High level of access to municipal services	S	• Low sanitation index	S
					• Egyptian Universities has conducted elaborate entomological research	T	• Human migration poses risk for increased disease transmission	S
							• Poor understanding of mosquito-borne disease transmission in Egypt Mosquito control operations not based on scientific information and data of target vector	S
							• Presence of breeding sites that are difficult to control	T
Tel Aviv	• Presence of mosquito control laws	P	• Restricted access to military sites where mosquitoes are known to be breeding	P	• New laws related to mosquito control are being written	P	• National security and terrorism threats makes control difficult	P
	• Good integrated mosquito control	T	• Short term funding for mosquito control	E	• Additional governmental funding for mosquito control is being provided	E	• New disease threats are causing a shift in funding	E
			• Lack of inetersectoral collaboration	T	• Public awareness	S	• Community view that national and local governing bodies are responsible for providing all solutions to problems	S
							• Geography puts Israel at risk for West Nile outbreaks	T
Puntarenas	• Government collaboration with community groups	P	• Limited training on vector biology and medical entomology for inspectors	T	• High level of acess to municipal services	S	• Buildings are built without regards to planning (no trained urban planners)	P
	• High inter-sector collaboration	P					• Lack of concordance between entomological indices and disease indices	T
	• Strong media campaign	S						
	• Good disease surviellance	T						
St. Augustine	• Presence of mosquito control laws	P	• Funding influenced by political climate	E	• Private sector may have interest in controlling mosquitoes	E	• Human behavioral practices may increase mosquito burden	S
	• Considerable funding	E	• Failure of insecticides	T	• Relatively low demographic pressure	S	• Changes in vector behavior in urban environment	T
	• Good integrated mosquito control	T	• Low inter-sector collaboration	T	• Increasing mosquito control education being offered to Ministry Officers	S		
					• Synergy of mosquito control may be feasible	T		
					• Technical support from international organizations	T		

Study site	Internal factors		External factors	
	STRENGTHS (Desirable practices)	WEAKNESSES (Non-desirable practices)	OPPORTUNITIES (Benefits to performance)	THREATS (Obstacles to performance)

P=Political/Legal: refers to the political will, bureaucracy, and laws influencing mosquito control

E= Economic: refers to the funding aspect of mosquito control operations

S= Social: refers to the social interactions and views, and community involvement in mosquito control operations

T= Technological: refers to all aspects of the biological and technical aspects of mosquito control operations

Table 5

Cross comparison of techniques used by each mosquito control program

Category	Study sites						
	Kisumu	Malindi	Cairo	Aswan	Herzliya	Puntarenas	St. Augustine
Legislation	+	+	ND	ND	+	+	+
Entomological surveillance	+	-	+	+	+	+	+
Epidemiological surveillance	+	+	+	+	+	+	+
Environmental management	+	+	+	-	+	+	+
Biological control	-	-	-	-	+	-	+
Chemical control	+	+	+	+	+	+	+
Public education	+	+	-	-	+	+	+
Activity reports	+	+	+	+	+	+	+
Training/continuing education	+	-	+	+	+	+	+
Inter-sector collaboration	+	+	+	+	+	+	+
Applied local research	-	-	-	-	+	+	+

ND: no available data; plus sign: technique used by mosquito control program, minus sign: technique not used by mosquito control program