Chapter 3

The Evolution of Entomological Research with Focus on Emerging and Re-emerging Mosquito-Borne Infections in the Philippines

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Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.78686

Abstract

This paper presented previous and current research efforts for medically important mosquitoes that serve as vectors of emerging and re-emerging diseases in the Philippines, in light of identifying the research gap that exists in the field of public health entomology in the country. This extensive review of the past and current research studies with regard to medical entomology and vector control also attempted to provide proper direction and insights for effective implementation of the country's vector control programs. All research studies conducted in the Philippines from 1958 up to the present that are related to the paper's interest and are available on Philippines' Department of Science and Technology and RITM databases were tracked. Results from this analysis imply that studies on public health entomology in the Philippines have evolved and have gone through various stages of development over time. However, the magnitude of research on medically important mosquitoes in the country is still insufficient for it to contribute comprehensively to integrated methods of vector management and totally eliminate mosquito-borne infections in the Philippines. It is recommended for researchers to work on the continuity of vector researches and explore further the diversity of the entomological aspects of the control of vector-borne diseases.

Keywords: *Aedes* mosquitoes, medical entomology research, Zika, chikungunya, Japanese encephalitis

1. Introduction

Mosquito-transmitted diseases continue to cause great problem to the public health situation of tropical countries like the Philippines. Dengue, the world's fastest-spreading mosquito-borne disease, brought burden to a total of 131,827 Filipinos in 2017 [1]. As climate change and global warming (which worsens every year) increase the likelihood and spread of many vector-borne diseases [2], the Philippines' public health has started to increase focus on other emerging and re-emerging mosquito-borne diseases such as the Zika virus, Japanese encephalitis, and chikungunya.

Zika virus (ZIKV) was mainly confined to the African continent until it was detected in Southeast Asia in the 1980s, then in the Micronesia in 2007, and, more recently, in the Americas in 2014, where it has displayed an explosive spread, as confirmed by the World Health Organization [3]. In the Philippines, the virus has been recorded as early as 1953 when a serological study detected 19 Zika-positive sera out of 153 samples tested [4]. In May 2012, amid the threat of ZIKV's global spread, a 15-year-old boy in Cebu City reported a subjective fever. By using real-time reverse transcription PCR targeting the gene that encodes the precursor of membrane protein, ZIKV RNA in the patient's serum sample was detected [5].

Meanwhile, two other neglected mosquito-borne diseases—chikungunya and Japanese encephalitis—recently made headlines in the Philippines because of unusual morbidity or mortality rates caused by the said viruses in the past few years.

In 2013, in the aftermath of Typhoon Haiyan, Region VI of the Philippines experienced two outbreaks of chikungunya fever in the provinces of Antique and Negros Occidental [6]. This was followed by another outbreak in Cavite in 2016 with more than 450 suspect cases. In the same year, a total of 6351 suspect chikungunya cases were reported throughout the country [7].

Japanese encephalitis (JE), on the other hand, caused nine deaths in the Philippines in September, 2017. This prompted the Department of Health to call on local executives and the public to intensify mosquito prevention and control measures at home and in the community, and to protect themselves from being bitten by mosquitoes, particularly in high-risk areas. The agency also started firming up plans to introduce JE vaccination among young children in 2018 [8].

The common epidemiological feature of these emerging and re-emerging diseases is that they are vectored by mosquitoes. Some mosquito vectors are specific to certain disease, while some are responsible for multiple diseases; and some control combinations are specific, while others are effective on several of them [9–11]. *Aedes* genus, for instance, are known vectors for numerous viral infections with *Aedes aegypti* and *Aedes albopictus* being the main vectors of the three diseases of interest in this chapter—dengue, chikungunya, and Zika virus.

In the absence of vaccine for many mosquito-borne diseases (except for Japanese B encephalitis and for dengue with limited reported efficacy and questions on its safety for those who have not contracted dengue), integrated vector management (IVM) remains the sole method to prevent transmission. IVM is the first line of defense against mosquito and other vector-borne diseases especially with the worsening effect of climate change, given that many vector-borne and zoonotic diseases (diseases involving vectors such as blood-feeding insects or animal hosts) exhibit some degree of sensitivity to climate [12].

The public health authorities in the country, including scientists and researchers must therefore pay attention as well on the aspect of medical entomology to look closely at the biological characteristics and behavior of disease vectors; and on how ecological and environmental factors affect their density and transmission for more holistic and integrated approach to vector control.

In the Philippines, current projects and researches on the entomological aspects of mosquito-borne diseases—from biological study of the vectors to their surveillance and control—are mainly conducted by the Department of Medical Entomology under the Research Institute for Tropical Medicine (RITM), the research arm on infectious and tropical diseases of the Philippines' Department of Health. Several private and public institutions in the country also conduct or support research with regard to public health entomology. These include the Philippine Council for Health Research and Development (PCHRD) of the Department of Science and Technology (DOST), the National Institute of Molecular Biology and Biotechnology, University of the Philippines Los Baños (BIOTECH-UPLB), the College of Public Health of the University of the Philippines Manila, and the University of San Carlos in Cebu.

This chapter attempts to present the previous and current research efforts for medically important mosquito vectors in the country in light of identifying the research gap that exists in the field of public health entomology in the Philippines; and to look for possible ways to come up with a continuous, sustainable, and integrated approach to vector research and their actual applications to reduce the burden of different vector-borne diseases in the country. This extensive review of the past and current projects or research in the country with regard to medical entomology and vector control is also critical to provide proper direction and insights for effective implementation of the country's vector control programs.

2. Methodology

To do the review, all relevant research studies conducted in the Philippines that are related to primary vectors of emerging and re-emerging mosquito-borne diseases in the country from 1958 up to the present were tracked (including unpublished university dissertations, as well as the recently concluded research projects conducted by RITM that are yet to be published). This chapter particularly paid attention to vectors of dengue, chikungunya, Zika virus, and Japanese encephalitis. Researches were divided into three main categories: vector biology, vector surveillance, and vector control.

All RITM-participated studies that are related to the subject of interest were included in the analysis. Details of the research studies that were not conducted or participated by researchers from RITM were obtained through the help of the online database Health Research and Development Information Network (HERDIN: http://www.herdin.ph/), the national health research repository of the Philippines which is managed by DOST's PCHRD. The research studies were acquired by using helpful keywords related to the subjects of interest of this chapter. A total of 153 studies from HERDIN and RITM list have qualified for inclusion in this chapter.

The flowchart below explains further details on the selection criteria of the studies that were included in this chapter (**Figure 1**).

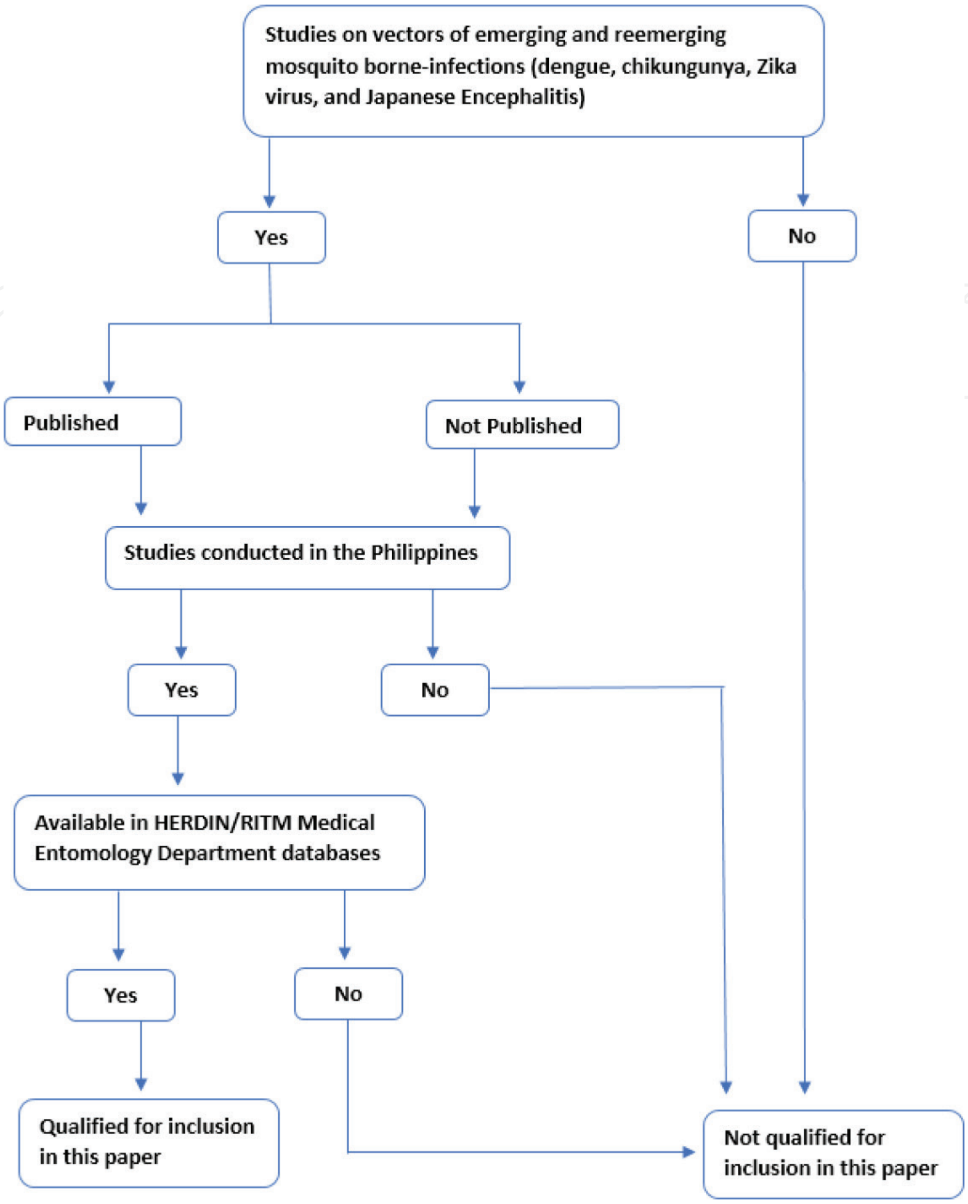

Figure 1. Flowchart for the selection of studies included in this chapter.

3. Results

3.1. Vector surveillance and control studies

The earliest recorded surveillance of mosquito vectors of public health importance in the Philippines was conducted by Ludlow [13] for her PhD dissertation which tackled the distribution of mosquito species in the Philippine Islands and the relation of their occurrence to the incidence of certain diseases in the country. Ludlow's studies of disease-bearing mosquitoes contributed greatly to the well-being of U.S. Army soldiers in the Philippines around the world during the time [14].

Meanwhile, Siler et al. [15] described in 1926 the definite dengue season in Manila and Lowland Luzon. The study suggested that conditions are favorable for mass reproduction of *Ae. aegypti* during dry season (March to May, inclusive) if a few heavy rains occur at intervals of 15–20 days; and during wet season (June to September).

In the late 1950s to 1960s, notable studies on mosquito vector surveillance and control were performed in the Philippines and its neighboring countries (**Table 1**) following a large epidemic of serious and often fatal cases of hemorrhagic febrile disease caused by mosquito bite in Manila in 1956 (with over 1200 cases and about 75 fatalities) and in Bangkok, Thailand (with nearly 2500 cases and about 250 fatalities) in 1958 [16].

The disease was described as a new disease and was referred to as the Philippine hemorrhagic fever but was later renamed dengue hemorrhagic fever (DHF) as more cases were reported in both Thailand and the Philippines [17]. However, according to Halstead [18], the association of dengue and chikungunya viruses in time and place with severe hemorrhagic disease has led many authors to assume that both viruses caused hemorrhagic fever.

Vector surveillance studies in response to hemorrhagic fever pandemic in Southeast Asia included the distribution of *Aedes* mosquitoes in Manila and Bangkok in 1960; observations of vectors of dengue hemorrhagic fever in the Philippines, Bangkok, and Singapore from 1956 to 1961; and epidemiological-entomological observations on Philippine hemorrhagic fever in 1968 [16, 19, 20].

Studies on vector control in the Philippines during this period mainly focused on potential larvicidal and adulticidal agents against mosquito vectors such as ordinary salt, benzyl isoquinoline alkaloids, and dichlorodiphenyltrichloroethane (DDT) [21–23].

Further studies on distribution of medically important mosquitoes in the Philippine islands were conducted the following decade (**Table 2**). In 1970, Baisas et al. [24] identified the distribution and abundance of medically important mosquito species in the Philippines for each

Research title	Year released
Newly recognized *Aedes aegypti* problems in Manila and Bangkok	1960
Entomological aspects of hemorrhagic fever epidemics in Bangkok, the Philippines, and Singapore	1961
Use of ordinary table salt against breeding of mosquitoes in artificial containers	1963
Control of the vector mosquitoes of hemorrhagic fever	1965
Susceptibility of common household pest mosquitoes to experimental infection with *Brugia malayi* microfilariae as compared to the principal vector	1966
A possible larvicidal Agent among the bis-benzyl isoquinoline alkaloids	1968
Epidemiological-entomological observations on Philippine hemorrhagic fever	1968
Distribution and seasonal abundance of mosquitoes in the University of the Philippines campus	1969

Table 1. List of vector control and surveillance studies in the Philippines, 1960–1969.

Research title	Year released
Determination of the distribution and abundance of mosquitoes in selected geographic areas	1970
Mosquitoes in Cebu City and adjacent area: an ecological survey	1971
On Philippine mosquitoes, VIII. The distribution of *Aedes aegypti* Linn. (Diptera: Culicidae) and its relationship to the spread of dengue hemorrhagic fever	1972
Mosquitoes in relation to public health in the Philippines with reference to the principal vector, species, and the diseases they transmit	1972
On Philippine mosquitoes, XII—Some ecological notes on two medically important mosquito species, *Aedes aegypti* and *Aedes albopictus*, in a selected geographic area of the UP College of Agriculture Campus in UP Los Baños, Laguna Province (Diptera: Culicidae)	1973
The mosquito control program at the Manila International Airport and vicinity (Philippines) with comments on problems encountered on the aerial transportation of mosquitoes	1973
On Philippine mosquitoes XIII—An inland survey of the distribution and relative prevalence of *Aedes aegypti* (Diptera: Culicidae) with reference to mosquito-borne hemorrhagic fever	1974
Epidemiological, virological, and entomological studies on dengue in the city of Manila	1979

Table 2. List of vector control and surveillance studies in the Philippines, 1970–1979.

month and designated zone in a span of 12 months. During the 12-month period surveillance, eight species implicated in the transmission of various diseases (malaria, filaria, dengue, hemorrhagic fever, Japanese B encephalitis, and chikungunya) were obtained. The study further implied that Japanese B encephalitis was most likely to occur in epidemic form at that time because of *Culex tritaeniorhynchus* and *Culex gelidus*.

Meanwhile, Schoenig [25] conducted an ecological survey of mosquito vectors in Cebu City and its adjacent areas in 1971 which found *Aedes aegypti* Linnaeus to be the primary species present in the area. He also came up with a taxonomic key on determining the species collected in the field.

From 1972 to 1974, Basio et al. [26–30] implemented a series of mosquito vector surveillance and control studies in the Philippines. These are composed of surveillance on mosquitoes in relation to public health in the Philippines with reference to the principal vector, species, and the diseases they transmit; a research on the distribution of *Aedes aegypti* Linn in the country and its relationship to the spread of dengue hemorrhagic fever; ecological notes on two medically important mosquito species, *Aedes aegypti* and *Aedes albopictus*, in a selected geographic area of the UP College of Agriculture Campus in UP Los Baños, Laguna Province; mosquito control program at the Manila International Airport (now Ninoy Aquino International Airport) and vicinity with comments on problems encountered on the aerial transportation of mosquitoes; and an inland survey of the distribution and relative prevalence of *Aedes aegypti* (Diptera: Culicidae) with reference to mosquito-borne hemorrhagic fever.

Toward the latter part of 1970s and earlier part of 1980s, further studies on entomological aspects of emerging mosquito-borne diseases in the Philippines and on control of their major vectors were carried out by local scientists.

Among these studies is a comprehensive vector surveillance study conducted by Salazar et al. [31] from 1978 to 1979, a survey of *Ae. aegypti* mosquitoes that used standard entomological procedures and calculations for adult and larval mosquito indices aside from obtaining information on the distribution and density of the species in the city of Manila. Salazar also investigated the entomological aspects of both dengue and malaria in 1984 [32].

In terms of vector control, additional aspects of mosquito reduction were explored in this period aside from utilizing insecticides, particularly in terms of generating insights on participatory approach of mosquito reduction in the community and modifying health-risk behaviors of the people living in the vicinities which are vulnerable to outbreak of mosquito-borne diseases. For instance, Cruz conducted a study on the effectiveness of community-based health program in *Aedes aegypti* control in 1982 [33].

A study on *Bacillus thuringiensis* (Bt), a bacterial microbe derived from soil, was also explored in search of safe and effective mosquito larvicide. In 1984, Jueco et al. [34] performed bioassay of *Bacillus thuringiensis (Bt) Israelensis* serotype H-14 against Philippine strains of *Aedes aegypti*, *Anopheles litoralis,* and *Culex quinquefasciatus* in some drainage canals in the city of Manila to test the susceptibility of the three species to the potential larvicide.

Padua et al. [35, 36] on the other hand, studied the *Bt* subspecies *morrisoni* [serotype H 8a: 8b] (PG-14) from 1982 to 1984 which was obtained from a soil sample in Cebu City. This isolate produced a spherical or irregular parasporal crystal, highly toxic to mosquito larvae but not to the silkworm, *Bombyx mori*, and adults of a daphnid. It was also negative for 13-exotoxin. All this is in contrast to the type strain. This isolate, being the first discovered from the tropics, is serologically different from Bt subsp. Israelensis, serotype H-14 [37].

Meanwhile, a study on Japanese encephalitis mosquito vectors in the Philippines rice fields by Llagas et al. [38] in 1989 presented information that are relevant to the understanding of the Philippine rice agro-ecosystem and its characteristics in relation to vector breeding.

Overall in 1980s (**Table 3**), the number of studies investigating the effectiveness of different interventions to reduce or eliminate the density of mosquito vectors or combination of vector surveillance and control studies is higher than studies on mere surveillance of mosquito vectors—the first time since research studies on medically important mosquito vectors in the country were implemented.

This trend continued to increase in the following decades (**Table 4**). In 1990s, researchers explored further on different aspects of mosquito control which include the use of different Philippine plants such as tubli (*Derris elliptica* Benth), guyabano (*Annona muricata*), and selected seaweed species as potential larvicide or insecticide against medically important mosquitoes [39–41]; the use of N,N-diethyl-meta-toluamide (DEET) formulations as mosquito repellents [42]; utilization of permethrin-treated curtains for control of *Aedes aegypti* in the Philippines [43]; further studies on different *Bacillus thuringiensis* strains as potential larvicide [44, 45]; and observations on the effectiveness of different community-based approaches on mosquito reduction including modifying the knowledge, attitude, behaviors, and practices of the people in the communities which are vulnerable to mosquito-borne disease outbreaks [46–48].

Research title	Year released
Studies on dengue hemorrhagic fever in the Philippines II. Entomological aspects	1980
A study on the effectiveness of community-based health program in *Aedes aegypti* control	1982
Bacillus thuringiensis isolated in the Philippines	1982
Isolation of a *Bacillus thuringiensis* (serotype 8a:8b) highly and selectively toxic against mosquito larvae	1984
Malaria and dengue hemorrhagic fever in the Philippines: entomological aspects	1984
Bioassay of *Bacillus thuringiensis* Israelensis serotype H-14 against Philippine strains of *Aedes aegypti*, *Anopheles litoralis* and *Culex quinquefasciatus*	1984
Strategies for control of Japanese encephalitis mosquito vectors in the Philippines rice fields	1989
Cemetery vase breeding of dengue vectors in Manila, Republic of the Philippines	1989

Table 3. List of vector control and surveillance studies in the Philippines, 1980–1989.

Research title	Year released
Ultrastructure study of *Bacillus thuringiensis*-treated *Aedes aegypti* larvae	1991
Comparison of the effectiveness of two DEET formulations against *Aedes albopictus* in the Philippines	1991
Distribution of *Aedes albopictus* mosquitoes in one urban and sub-urban communities in the Philippines; an ovitrap and larval survey	1991
Distribution of *Aedes Aegypti* and *Aedes albopictus* in one urban and sub-urban communities in the Philippines—an ovitrap and larval survey	1992
Seasonal abundance of dengue vectors in Manila, Republic of the Philippines	1993
Knowledge, attitudes, and practices of Filipino Mothers regarding the dengue fever syndrome: implications toward preventive interventions	1993
Antibacterial, antifungal and larvicidal properties of selected seaweeds in Bolinao, Pangasinan	1994
Biology and control of *Aedes* mosquito vectors of dengue/dengue hemorrhagic fever in the Philippines	1995
Community-based control of dengue hemorrhagic fever: a 5-year prospective intervention program (1991–1995)	1996
Toxicity effect of effluents from selected food-processing industries along Butuanon River on larvae of *Aedes* spp.	1997
Update: Japanese encephalitis virus Activity in the Philippines	1999
The insecticidal effect of tubli (*Derris* sp.) root crude extract on *Aedes* mosquito larvae	1999
Use of permethrin-treated curtains for control of *Aedes aegypti* in the Philippines	1999
A community field practice report in Sitio Bagong Pook, Tanza, Cavite: control and prevention of dengue fever	1999
The larvicidal effect of guyabano (*Annona muricata*) leaf extract on *Aedes aegypti* mosquito	1999
Effects of mutants of *Bacillus thuringiensis* subsp. Israelensis on mosquito larvae (*Aedes aegypti*)	1999

Table 4. List of vector control and surveillance studies in the Philippines, 1991–1999.

The advent of the new millennium brought along major ecological and environmental issues globally such as overpopulation, urbanization, and climate change which affected the public health situation of the world, including the proliferation of mosquito-borne diseases. In response to these phenomena, new approaches on vector surveillance studies were employed by researchers on public health entomology in the Philippines, especially in the latter part of the 2000s when scientists all over the world have started to form a consensus and agreed that human-induced climate change is really happening (**Table 5**).

Aside from conducting an integrated research on the aspects of both vector surveillance and control, research studies in the Philippines also started to identify and analyze factors which are deemed critical on multiplication of mosquito vectors and on increase in incidences of vector-borne diseases in tropical setting such as rainfall, humidity, and temperature. This is to contribute to a proactive vector management efforts amid the abnormal climatic patterns and extreme weathers that happen across the globe because of climate change, which the climate scientists claim as the "current normal."

Among the studies of this kind include the analytical study on the relationship between rainfall, temperature, and humidity and the number of dengue fever cases in admitted patients in Northern Mindanao Medical Center from 1998 to 2007 by Seeto et al. [49] in 2008; correlation of climatic factors and dengue incidence in Metro Manila, Philippines by Sia Su [50] in 2008; and Reyes's study on rainfall, temperature, relative humidity, and dengue cases in Metro Manila in 2009 [51].

Studies on biological methods for vector control were also explored in this period. Reyes et al. [52, 53] conducted two studies on the efficacy of Philippine species of *Mesocyclops* (Crustacea: Copepoda) as a biological control agent of *Aedes aegypti* in 2004 and 2005.

According to WHO, biological control is based on the introduction of organisms that prey upon, parasitize, compete with, or otherwise reduce populations of the target species. Against *Aedes*, a selection of larvivorous fish species and predatory copepods (small freshwater crustaceans) are effective against the immature larval stages of vector mosquitoes [54].

Research studies using the earlier approaches for vector control were further explored during this period such as screening of Philippine plants and trees for larvicidal activity or repellant against *Aedes aegypti* and other medically important mosquitoes; and observations on the behavioral change of the communities vulnerable to outbreaks of mosquito-borne diseases through information dissemination.

With regard to Japanese encephalitis vectors, Bertuso et al. [55] conducted a study observing the ecology of *Culex tritaeniorhynchus, Cx. Gelidus,* and *Cx. bitaeniorhynchus* in the province of Bulacan in 2006 with special reference to their aquatic habitat.

The trend on integrated approaches to the conduct of research on vector surveillance and control continued in 2010s (**Table 6**). Researchers utilized modeling and simulation techniques to understand in a more holistic way the implications of climate change and other environmental factors on the density of medically important mosquitoes and dengue incidences in different areas of the country. For instance, the recently concluded research project of RITM

Research title	Year released
People's knowledge and practice and *Aedes aegypti* infestation in Cebu City, Philippines and implications for community-based dengue control	2000
The larvicidal potential of extract from the leaves of lagnob (*Ficus septica* Burm.f.) on *Aedes* mosquito	2000
Identification of dengue larvae via larvitraps at Manila Central University (a preliminary study)	2000
People's knowledge and practice and *Aedes aegypti* infestation in Cebu City, Philippines and implications for community-based dengue control	2000
The efficacy of abate 1 sg and culinex plus s in controlling *Aedes albopictus* larvae	2002
Knowledge, attitudes, and practices among residents of Brgy. Tinajeros, Malabon Metro Manila regarding dengue prevention	2002
Screening of Philippine plants for larvicidal activity on *Aedes aegypti*	2003
An interventional study on the effectiveness of the basic training course on dengue prevention and control among barangay health workers in Piñan, Zamboanga del Norte	2003
The seasonal pattern of occurrence of *Aedes* mosquito dengue vector	2002
The association between local meteorological factors and hospital admissions of dengue hemorrhagic fever in Iloilo Province, Philippines	2002
Establishment of sensitive vector indicator for dengue surveillance	2002
The effectiveness of larval surveillance-integrative approach strategy in relation to prevalence and density of the *Aedes* larvae	2003
The effect of puppetry as an educational intervention approach on the knowledge, attitude and practices regarding dengue hemorrhagic fever prevention and control among grade school children in Lawaan Elementary School, Banonong, Dapitan City	2004
Students' perceptions about mosquito larval control in a dengue-endemic Philippine city	2004
Species of *Mesocyclops* (Crustacea: Copepoda) as a biological control agent of *Aedes aegypti* (Linnaeus)	2004
Evaluation of the present dengue situation and control strategies against *Aedes aegypti* in Cebu City, Philippines	2005
A preliminary study on the mosquito repellent effect of tea tree (*Melaleuca alternifolia*) oil	2005
Survey of freshwater Copepods (Crustacea) in selected areas of Luzon with dengue cases	2005
A comparison of an integrative learning method and problem-based learning method as dissemination tools about dengue hemorrhagic fever among public elementary school teachers in Zamboanga City	2005
Evaluation of the present dengue situation and control strategies against *Aedes aegypti* in Cebu City, Philippines	2005
Survey of dengue vectors in Barangay 674 "Estero de Tanque", Paco, Manila	2005
The effect of interventional program on the larval indices of *Aedes Aegypti* in selected Barangays Isabela City, Basilan	2006
Aedes sp. surveillance using ovitrap technique in Barangay Sta. Cruz, Makati City, Philippines	2006
Ecology of mosquito vectors of Japanese encephalitis in Malawak, Bustos, Bulacan [Philippines] with special reference to their aquatic habitat	2006
The mosquito attracting power of powdered: *Ruellia tuberosa* (waterbomb)	2006

Research title	Year released
The effect of interventional program on the larval indices of *Aedes Aegypti* in selected Barangays Isabela City, Basilan	2006
Dengue mosquito ovitrapping and preventive fogging trials in the Philippines	2007
Perceived self-efficacy to plan and execute an environmental action plan for dengue control among Filipino University students	2007
Dengue vector surveillance in barangay Gumatdang, Itogon, Benguet	2007
Aedes survey of selected public hospitals admitting dengue patients in Metro Manila, Philippines	2008
Entomological survey of dengue vectors as basis for developing vector control measures in Barangay Poblacion, Muntinlupa City, Philippines	2008
Larvicidal effect of *Lansium domesticum* Correa (Sapindales: Meliaceae) exocarps and seeds on 3-day old *Aedes aegypti* Linnaeus (Diptera: Culicidae) mosquito larvae	2008
An evaluation on the impact of the dengue control program on the knowledge, attitudes and practices of the residents of barangays Macasandig and Indahag, Cagayan de Oro City, 2007	2008
An analytical study on the relationship between rainfall, temperature and humidity and the number of dengue fever cases in admitted patients at the Northern Mindanao Medical Center from 1998–2007	2008
Correlation of climatic factors and dengue incidence in Metro Manila, Philippines	2008
Mosquito vectors and dengue cases in Manila	2009
Rainfall, temperature, relative humidity and dengue cases in Metro Manila, Philippines	2009
Enhanced development of dengue mosquito vector (*Aedes aegypti* Linnaeus) larvae feeding on maize (*Zea mays* Linnaeus) pollen under laboratory conditions	2009
Larvicidal activity of coconut fatty alcohol sulfate (CFAS) o *Aedes (stegomyia) aegypti* (Linnaeus 762)	2009

Table 5. List of vector control and surveillance studies in the Philippines, 2000–2009.

on the effect of weather patterns in predicting mosquito density and count of dengue cases in different locations in the Philippines used multiple regression analysis to come up with models containing predictor variables that contribute to the density of mosquitoes in the selected site. The study then came up with the best model on predicting mosquito density and count of dengue cases for particular locations using statistical computations.

Buczak et al. [56], on the other hand, built prediction models in 2014 for future dengue incidence in the Philippines that is capable of being modified for use in different situations; for diseases other than dengue; and for regions beyond the Philippines. This model predicted high or low incidence of dengue in the Philippines 4 weeks in advance of an outbreak with high accuracy, as measured by positive predictive value (PPV), negative predictive value (NPV), sensitivity, and specificity.

In Cebu City, Miksch et al. [57], used modeling and simulation techniques to understand how dengue spread in a community in 2015. The research team developed an agent-based model for simulating dengue epidemics which modeled human and mosquito agents with detailed agent's behavior, mosquito biting rules, and transmissions. Featuring a modular approach,

Research title	**Year released**
Insecticidal activity of *Cucurbita maxima* Duch. var. suprema (squash) leaf blades and *Piper nigrum* Linn. (Black pepper) seeds against *Aedes aegypti* mosquitoes	2010
Best practices in dengue surveillance: a report from the Asia-Pacific and Americas Dengue Prevention Board	2010
Antigen sandwich ELISA predicts RT-PCR detection of dengue virus genome in infected culture fluids of *Aedes albopictus* C6/36 cells	2010
Dengue vector surveillance methods in Muntinlupa City, Philippines	2011
Climate change and incidence of dengue fever (DF) and dengue hemorrhagic fever (DHF) in Iligan City, Lanao del Norte, Philippines	2011
Climatic factors affecting dengue fever and dengue hemorrhagic fever incidence in Makati City	2011
A study on the effect of utilizing school-based dengue education on the knowledge, attitude and practices of elementary students on dengue prevention and control in Tampilisan Central School, barangay Poblacion Tampilisan, Zamboanga del Norte	2011
Development of natural-based mosquito repellent lotion against dengue fever	2011
The effectiveness of *Ocimum basilicum* (sweet basil) extract as a mosquito (female *Aedes aegypti*) repellant: basis for information dissemination as a potential alternative measure for preventing mosquito bites	2011
The effectiveness of health teachings on the level of knowledge and degree of compliance on dengue awareness program as mandated by the department of health among selected residents in Barangay Labangon, Cebu City	2011
Evaluation of a peridomestic mosquito trap for integration into an *Aedes aegypti* (Diptera: Culicidae) push-pull control strategy	2012
Eco-bio-social research on dengue in Asia: a multicountry study on ecosystem and community-based approaches for the control of dengue vectors in urban and peri-urban Asia	2012
Effects of aqueous and pelletized admixture of *Piper nigrum* L on the oviposition behavior of *Aedes aegypti* mosquitoes and its larvicidal-ovicidal activity	2012
Community-based dengue vector control: experiences in behavior change in Metropolitan Manila, Philippines	2012
Operational efficiency and sustainability of vector control of malaria and dengue: descriptive case studies from the Philippines	2012
Multi-functional controlled release system for fragrant and mosquito-repellent finishing in cotton fabrics	2012
Philippine water bug effective biological control for dengue	2012
Field evaluation of ovitraps with *Piper nigrum* to assess its larvicidal and oppositional effects on dengue mosquito vectors	2012
Rainfall, temperature and the incidence of dengue in Central Visayas, Philippines are not correlated	2012
The key breeding sites by pupal survey for dengue mosquito vectors, *Aedes aegypti* (Linnaeus) and *Aedes albopictus* (Skuse), in Guba, Cebu City, Philippines	2012
The effect of climate change in the occurrence of dengue cases	2012
Review: geographical information systems for dengue surveillance	2012

Research title	Year released
Estimating dengue vector abundance in the wet and dry season: implications for targeted vector control in urban and peri-urban Asia	2012
A comparative study between hay infusion baited ovitrap with rain water baited ovitrap by counting the numbers of mosquito eggs	2012
Medically important mosquitoes (Diptera: Culicidae) identified in rural barangay Binubusan, Lian, Batangas Province, Philippines	2012
Baseline and key container survey for *Aedes aegypti* and *Aedes albopictus* in Albay Province, Philippines	2012
Medically important mosquitoes (Diptera: Culicidae) identified in rural barangay Binubusan, Lian, Batangas Province, Philippines	2012
Water quality and *Aedes* larval mosquito abundance in Caloocan city, Philippines	2012
The impact of climate change on the prevalence of dengue cases in the province of Albay	2013
Entomological survey of artificial container breeding sites of dengue vectors in Batasan Hills, Quezon City	2013
Natural transovarial transmission of dengue viruses in *Aedes aegypti* (Diptera: Culicidae) in Cebu City, Philippines	2013
Health promotive management interventions on the level of health care practices against dengue hemorrhagic fever among selected mothers in Barangay Guadalupe, Cebu City	2013
The effectiveness of fragrant pandan plant (*Pandanus amaryllifolius* Roxb.) prop root extract as a mosquito (*Aedes aegypti*) larvicide	2013
The larvicidal activity of brown algae *Padina minor* (Yamada 1925) and *Dictyota linearis* (Greville 1830) against the dengue vector, *Aedes aegypti* (Linn 1762) (Diptera: Culicidae)	2013
Effect of *Aedes aegypti* exposure to spatial repellent chemicals on BG-Sentinel™ trap catches	2013
Larvicidal effect of ampalaya (*Momordica charantia*) fruit juice on *Aedes* mosquito larvae	2013
Dengue knowledge and preventive practices among rural residents in Samar Province, Philippines	2013
Knowledge and practices of mothers of Sitio Riverside barangay Sambag II Cebu City on dengue fever: its disease transmission and prevention	2013
The relationship between the level of awareness on the prevention of dengue fever and their practices of full-time mothers in Sitio Malibu, Barangay Subangdaku, Mandaue City: a basis for information dissemination on the prevention of dengue fever	2013
Socioeconomic status and level of knowledge on environmental measures on dengue hemorrhagic fever among residents in Sitio Sudtungan, Basak, Lapu-lapu City: proposed guidelines to enhance awareness and prevention on dengue fever	2013
Laboratory observations on the use of *Diplonychus rusticus* as a potential biological control agent on Japanese encephalitis vector	2013
Preliminary screening of Citrus microcarpa (calamansi) seed oil extract as a potential larvicide against *Aedes aegypti*: a dengue fever mosquito	2014
Prediction of high incidence of dengue in the Philippines	2014
Knowledge, attitudes, perceptions and practices related to ovicidal-larvicidal traps for dengue control among households in one barangay in Quezon city	2014
Percent survival of dengue mosquito vector (*Aedes aegypti*) larvae feeding on rice (*Oryza sativa*) pollen under laboratory conditions	2014

Research title	Year released
Transovarial transmission of dengue virus in *Aedes aegypti*: a case in Quezon City, Philippines	2014
Analysis of climate variability and dengue occurrence in social-ecological systems: the case of Bay, Los Baños and Calamba in Laguna, the Philippines	2015
The effect of cogon grass (*Imperata cylindrica*) and carabao grass (*Paspalum conjugatum*) leaf extract on mortality of *Aedes aegypti* larvae	2015
The effectivity of Lanzones (*Lansium domesticum*) peelings' extract as mosquito repellant	2015
Isolation and identification of *Bacillus thuringiensis* from *Harpaphe haydeniana* and its entomotoxic evaluation against *Aedes* and *Culex* larvae	2015
An agent-based epidemic model for dengue simulation in the Philippines	2015
Identification of mosquito species in brown sugar and yeast mosquito trap	2015
CMOS RC oscillator using 0.35 micron for portable mosquito-repel circuit	2015
Effect of temperature, relative humidity and rainfall on dengue fever and leptospirosis infections in Manila, the Philippines	2016
Fabrication of a nanoparticle-based sensor for the detection of dengue virus-3 in *Aedes aegypti*	2016
Determinants of transmission risk and the role of vector pupal presence in the development of integrated approaches to dengue control in Muntinlupa City, The Philippines	2017
BG-Sentinel™ trap efficacy as a component of proof-of concept for push-pull control strategy for dengue vector mosquitoes	2017
Evaluation of a spatial repellent push-pull strategy for the control of *Aedes aegypti* using experimental huts in Western Thailand	2018
Effect of weather patterns in predicting mosquito density and count of dengue cases in six locations in the Philippines	2018

Table 6. List of vector control and surveillance studies in the Philippines, 2010–2018.

this method provides flexibility and allows functionalities that are easy to manage and to communicate. The model was parameterized and calibrated to simulate the 2010 dengue epidemic in Cebu City, Philippines. The study provided insights into the spreading process of dengue. It revealed that the changing mosquito population during rainy season has a great impact on the epidemic. With this, the study showed how further research on that matter using models and extended biological studies might lead to a better understanding of the dengue spreading process, and eventually to more effective disease control.

Meanwhile, Duncombe et al. [58] suggested the use of geographical information systems (GIS) for dengue surveillance, citing the advancement of GIS technology and its potential to greatly assist dengue prevention and control, as it allows further investigation of surveillance data through spatial statistical analyses and visualization of patterns and relationships between disease and the environment. The paper added that open access applications enable all countries to use this technology, including those nations with limited resources and that the advances in open access GIS technologies should be viewed as a catalyst for increased global collaboration, where information sharing and public health planning are prioritized to achieve common goals.

The use of more sophisticated biological and computational tools for vector control in the country such as molecular biology, nanotechnology, bioinformatics, or combination of these tools was also explored in the recent years. Among the studies that utilized these tools is the study by Contreras et al. [59] which fabricated a nanoparticle-based sensor using DNAzyme-functionalized dextrin-capped gold nanoparticles to detect the presence of dengue virus serotype-3 (DENV-3) in *Aedes aegypti*. In this research, the fabricated nanoparticle-based sensor can detect target concentration for as low as 0.1 μM using synthetic DENV-3 target and 5×10^2 PFU/mL using extracted RNA from *A. aegypti*. The nano-biosensor presented in this study provides a simple, faster, "greener," and portable way of detecting the DENV-3 in mosquitoes for epidemiological purposes.

Cruz et al. [60], on the other hand, devised a CMOS RC oscillator in 2015 that operates at frequency based on the wing-beat frequency of male mosquitoes and dragonflies, in order to produce ultrasonic signal that repels biting female mosquitoes. According to the researchers, this microelectronic CMOS oscillator can be further developed into portable and wearable mosquito-repel circuits, and can help improve the nonoccurrence of malaria and dengue in the country.

Meanwhile in RITM, the Department of Medical Entomology established partnership with the *World Mosquito Program* of Monash University in Australia to pilot test the introduction of *Wolbachia* (a naturally occurring bacteria from other insects) into *Aedes aegypti* eggs. The said bacteria reduce the ability of mosquitoes to transmit harmful human viruses such as dengue, chikungunya, and Zika when optimum density is present in female adults.

3.2. Vector biology and life history studies

One of the earliest peer-reviewed and comprehensive studies on biological characteristics of *Aedes Aegypti* in the Philippines is the study conducted by Del Rosario in 1961 which described some bionomic features of *Ae. aegypti* under laboratory conditions using an artificial colony. The study revealed that the development of *Ae. aegypti* from egg to adult takes about 2 weeks or more under ordinary room temperature (24–28°C). Oviposition follows in 4 or 5 days upon taking first blood meal (2 or 3 days after emergence). The female eats again 2 or 3 days later. Based on researcher's observations, *Ae. aegypti* species eat as many as eight times during its lifetime in the laboratory. The average interval between blood meals is 3.4 days. They laid eggs after almost every blood meal. However, there were instances where they had to take several blood meals before laying eggs. The number of eggs laid per oviposition ranges from 15 to 140 with an average of 57. The number of eggs by adults fed by chicken blood is significantly higher than those fed by human blood with an average of 76 [61].

Another study on *Ae. aegypti* revealed that certain laboratory strains of *Ae. aegypti* differ significantly and consistently in their choice of oviposition substrate. Based on the experiment conducted by Schoenig in 1968, the strain differences are not essentially affected by environmental influences and the stability of this reaction indicates genetic control. The researcher further noted that oviposition on a solid surface (paper) is the wild-type character. There is evidence that this character may be largely controlled by a single gene with incomplete dominance which linked to sex on chromosome 1. The study also indicates that behavioral character in mosquitoes can be measured and the genetic basis of mosquito behavior can be further investigated [62].

In 2012, a study on life history, fecundity, and blood feeding time of *Aedes albopictus*, another important vector of dengue viruses in the Philippines, was conducted by Aguila and Caoili under laboratory conditions (26.7 ± 0.9°C and 83 ± 5.7% RH). The controlled experiment revealed that the average development time of each life stages is as follows: eggs, 1.84 ± 0.8 days; larval stage: first instar, 2.31 ± 0.5 days; second instar, 1.11 ± 0.1 days; third instar, 1.12 ± 0.1 days; fourth instar 1.33 ± 0.2 days; pupal stage, 1.94 ± 0.1 days; and 3.91 ± 1.2 days for the adult longevity. The observed total developmental time from egg to adult was 13.55 ± 1.0 days. Female *Ae. albopictus* laid an average of 46.2 ± 32.3 eggs. Mortality factor from egg to pupal stage was K = 0.3808. Meanwhile, the researchers observed that the peak feeding time of *Ae. albopictus* regardless of age was at 07:00H, which is the first exposure period to the host. Additional peak biting time of 6- and 7-day-old females was at 10:00H, while that of 3-day-old females was at 21:00H and 03:00H. The study's results provide insights on effective mosquito management control strategy to prevent *Ae. albopictus* vectorial capacity anytime of the day [63].

Researchers also took advantage of bioinformatics and other innovative tools to gain further insights on the physiological features of vector mosquitoes. For instance, Sendaydiego et al. [64] identified the intraspecific divergence in wing shape and venation in *Aedes aegypti* using landmark-based geometric morphometrics. Results of the relative warp analysis showed some intraspecific variation in the wing outline of *Ae. aegypti*. The observed morphological disparity in wing shape suggests a possible morphological divergence among populations of *Ae. aegypti*.

In 2014, Alcantara constructed a homology model of *Ae. aegypti* chorion peroxidase enzyme and identified potential inhibitors of chorion peroxidase by computational method to predict the three-dimensional (3D) structure of *Ae. aegypti* chorion peroxidase. This study is significant on dengue vector control as development of ovicidal compounds targeting chorion peroxidase would complement existing larvicidal and adulticidal compounds for control of *Ae. aegypti* [65].

Table 7 shows the list of vector biology and life history studies in the Philippines from 1961 to 2014.

3.3. Distribution of vector research per decade, category

Studies on mosquito vectors of interest collected in this chapter were grouped according to decade they were released, ranging from 1958 up to the present. A total of 153 locally conducted studies were collected from RITM and HERDIN databases. The breakdown of number of studies conducted per decade is the following: 1 in 1950s, 11 in 1960s, 10 in 1970s, 9 in 1980s, 17 in 1990s, 39 in 2000s, and 66 in 2010s (**Figure 2**).

Except for 1970s and 1980s, there is an increasing trend on the number of studies conducted in the country over time. Decline on number of research in the 1970s and 1980s may be explained by the political turmoil and instability in the country during these decades which probably affected the funding of research in the Philippines. The country's political climate only stabilized in the latter part of the 1980s when transition in the Philippine government occurred, the first time in more than 20 years.

http://dx.doi.org/10.5772/intechopen.78686

Research title	Year released
Studies on the biology of Philippine mosquitoes, I—some bionomic features of *Aedes aegypti*	1961
Studies on the biology of Philippine mosquitoes, II—observations on the life and behavior of *Aedes albopictus* (Skuse) in the laboratory	1963
Strain variation in *Aedes aegypti*	1968
Host-induced modification of dengue-2 virus surface antigens in *Aedes albopictus* cells	1973
Recapitulations on changes in dengue virus properties and the etiology of dengue hemorrhagic fever	1976
Notes on the karyotype of two Philippine Aedine mosquitoes	1989
Biology and control of *Aedes* mosquito vectors of dengue/dengue hemorrhagic fever in the Philippines	1995
Production of viral antigens in culture fluid of C6/36 mosquito cell line infected with dengue type 4 virus strains isolated from patients with different clinical severities	2010
Antigen sandwich ELISA predicts RT-PCR detection of dengue virus genome in infected culture fluids of *Aedes albopictus* C6/36 cells	2010
Life history and blood feeding activity of a Philippine population of *Aedes albopictus* Skuse (Diptera: Culicidae) under laboratory conditions	2012
Describing wing geometry of *Aedes Aegypti* using landmark-based geometric morphometrics	2013
In silico identification of potential inhibitors of dengue mosquito, *Aedes Aegypti* chorion peroxidase	2014

Table 7. List of vector biology and life history studies in the Philippines, 1961–2014.

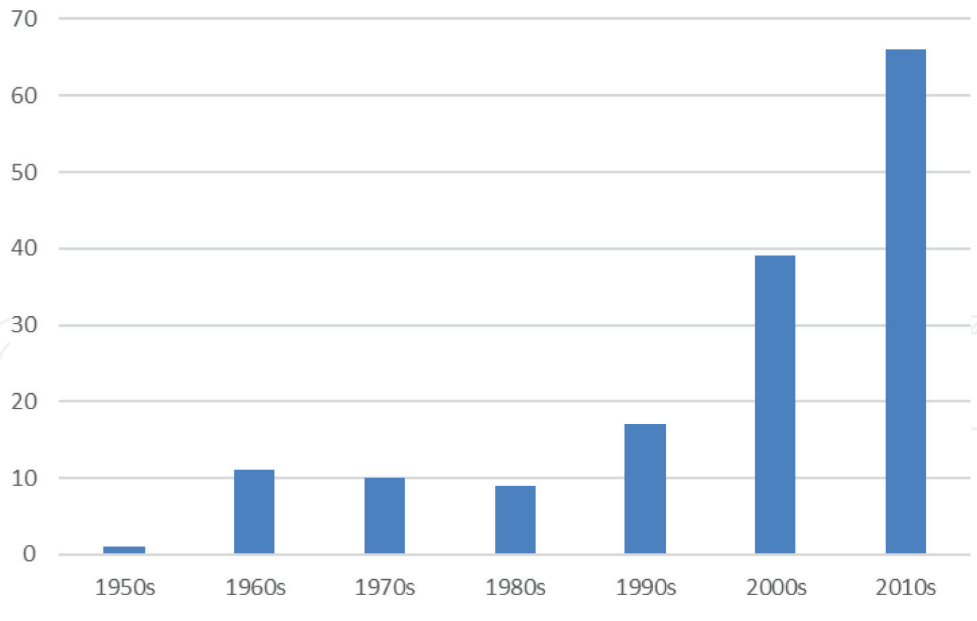

Figure 2. Distribution of mosquito vector studies per decade from 1950s to 2010s.

Research outputs following the decade of shift of administration in the country almost doubled from 9 in the 1980s to 17 in the 1990s. The increasing trend of research outputs on medical entomology further continued the following decades.

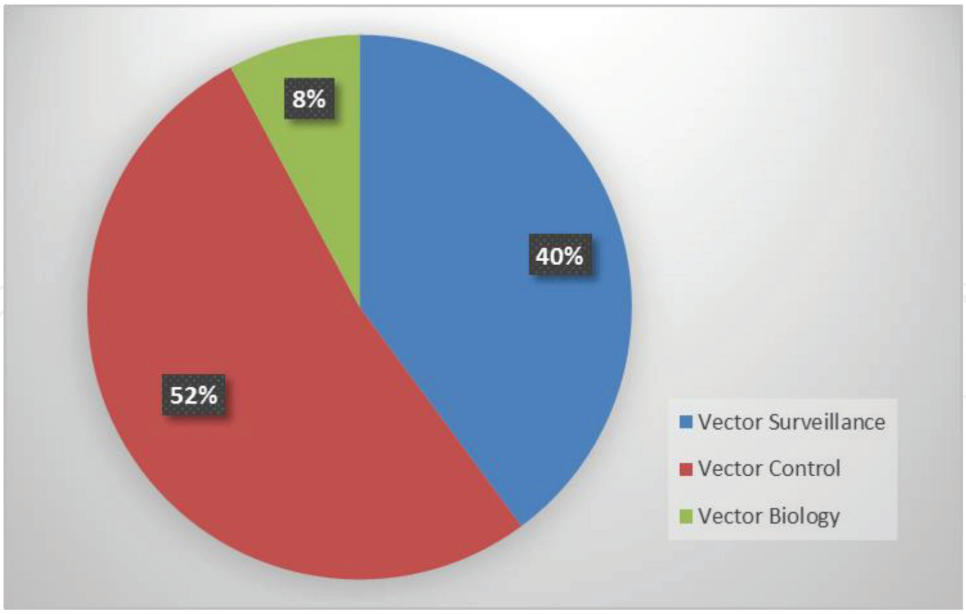

Figure 3. Distribution of mosquito vector studies according to category.

In terms of distribution of studies with regard to their respected categories, a total of 59 research studies (40%) fall under the Vector Surveillance Category, 79 studies (52%) fall under Vector Control Category, and 13 studies (8%) fall under Vector Biology Category (**Figure 3**).

The number of vector surveillance researches was prominent during the first decades covered in this study. By 1980s until the present, however, different aspects of mosquito vector control were explored by researchers either by means of chemical control, biological control, or environmental management, the third strategy includes modifying health-risk behaviors of the community which are vulnerable to mosquito-borne diseases outbreak.

Among the three categories of vector research, studies on the biological aspect of medically important mosquitoes seem to be lagging behind, comprising only about 9% of the total number of researches retrieved. By 2010s, however, more researchers have become interested on the biological characteristics of medically important mosquitoes in the country, with six research studies on this subject implemented in just a span of 6 years (2010–2015).

4. Conclusion and recommendation

The entomological aspect of the control and prevention of mosquito-borne diseases in the Philippines is oftentimes neglected by the public health researchers and practitioners. In essence, however, the field of medical entomology and its underlying science should be the first line of defense on management and control of vector-borne diseases in the country. Overall, it is safe to say that the studies on public health entomology in the Philippines have evolved and have gone through various stages of development overtime, as presented in this chapter. If in the earlier years, scientists were more focused on surveillance of medically important mosquitoes, the research concentration has shifted to vector control halfway of the period covered in this chapter. It also turns out that the research studies on public health entomology in the country, particularly on emerging and re-emerging mosquito-borne infections, are becoming more proactive and can serve as early warning for impact reduction, instead of merely responding during the period of outbreaks and epidemics. Specifically, public health entomology researches have looked at the broader point of view in terms of mass reproduction of mosquito vectors, taking into consideration different factors that affect their density such as globalization, climate change, overpopulation, and urbanization.

However, it can also be implied from this analysis that the number of studies that concern this chapter's interest remains low but thematically, these studies follow universal trends. Newer aspects of vector control research were explored—from the use of ordinary salt as mosquito larvicide to the optimization of breakthrough technologies such as genetic modification, molecular biology, and bioinformatics to dramatically reduce mosquito-borne infections in the country.

Nevertheless, the magnitude of research on medically important mosquitoes in the Philippines is still insufficient for it to contribute comprehensively to integrated methods of vector management and to totally eradicate mosquito-borne infections. Integrated vector management provides a sound conceptual framework for deployment of cost-effective and sustainable methods of vector control. This approach allows for full consideration of the complex determinants of disease transmission, including local disease ecology, the role of human activity in increasing risks of disease transmission, and the socioeconomic conditions of affected communities [66].

Reasons for lack of merit of Philippine-conducted vector research include the absence of interests of the researchers to publish their studies; the discontinuation of research topics that need further validation due to lack of financial support; or lack of initiative from the researchers to further pursue their studies until empirical evidences are found, especially those who only conducted research to complete their university dissertations. On the other hand, some research studies identified in this chapter are practically a repeat of studies which were previously done and this could have been avoided if an online reference or database providing a rundown of all aspects of entomological research conducted in the country is available.

Researchers should work on the continuity of vector researches and explore further the diversity of the entomological aspects of the control of vector-borne diseases. The diversified approach to vector research offers the public health authorities some leeway and convenience of having a variety of choices for intervention to vector reduction in different mosquito-endemic areas since approaches to mosquito eradication are oftentimes location specific. Despite emergence of sophisticated tools for vector control research, studies on cheap but effective solution for vector control should still be explored since in many cases, approaches to mosquito source reduction in affected areas need not to be too expensive.

It is thus recommended for the National Government to set up the country's Center of Excellence for Medical Entomology which will oversee the activities for public health entomology across the country, institutionalize a nationwide network of public health entomologists, spearhead the establishment of more satellite centers in different parts of the country to immediately address area-specific needs as they arise, and serve as the curator of medical entomology-related data and researches for a more organized manner of storage, retrieval, and application of these information on public health entomology and vector control.

But perhaps the most crucial part of public health entomology research is the communication and extension of these studies' potentials to the right people and concerned stakeholders. These include the public, policy-makers, mass media, local government units, and local health workers. After all, the end-goals of these researches are to be applied and utilized in the actual public health situations in the country, and in more fortunate scenarios, to serve as early warning to avoid the large-scale effect to public health of emerging and re-emerging mosquito-borne infections.

The stakeholders mentioned above need to be oriented on the importance of public health entomology and vector control so that they could support the conduct of further studies on the entomological aspects of mosquito-borne infections and even on the actual application of these researches through policy legislation and local government programs. As a science communication maxim says, "a research not communicated is like a research not done at all."

For instance, in a Dengue Vector Surveillance Workshop conducted by the Department of Health in 2014, insights were solicited among the regional health workers on why dengue vector surveillance (DVS) was not fully implemented in the country.

Inputs from the DVS workshop revealed that only 25% of the provinces and 6% of the municipalities/cities and barangays in the Philippines have completed the legislation to implement DVS in their localities. An alarming rate of 69% at the provincial level, 76% at the municipal/city level, and 94% at the barangay level has no legislation at all to implement the said activity. In terms of budget allocation, there is actually no city/municipal local government unit (LGU) and barangay LGU which has fully designated budget for the conduct of DVS, while only 6.25% of the provincial LGUs have complete budget for the said activity [67].

The Philippine Local Government Code mandates local government units (LGUs) to implement activities and programs for vector control at provincial, city, and smaller municipal levels down to the barangay ("village" unit). Theoretically, this mandate is an ideal setup since local government units are more familiar with the demographics of their localities, (including the residents) than those from the National Government. But the lack of awareness of most LGUs on the importance of vector control does not translate to policy legislations and informed decisions to include vector surveillance as one of their priorities.

In the same manner, there is a need to review the national government policies in reference to factors that contribute largely to emerging and re-emerging mosquito-borne diseases. There is also a need to increase awareness of the public, especially the young aspiring scientists and researchers, that selected Philippine agencies have highly significant budget for the conduct of researches to encourage them to devote time toward the pursuit of scientific evidences, including those from the aspect of prevention of emerging and re-emerging mosquito-borne infections.

The public, on the other hand, especially those who reside in areas which are endemic to mosquito-borne infections may also provide insights on their communities' practices for vectors' source reduction, for the control of these vectors' mass reproduction, and even on the vectors'

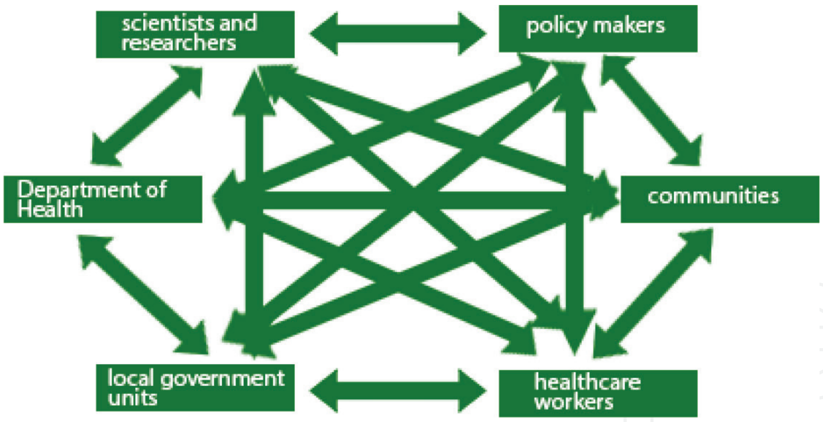

Figure 4. Framework for dynamic communication/exchange of information among the major stakeholders of public health entomology for the conceptualization, implementation, and actual application of medical entomology research.

behaviors, physical, and biological characteristics or their density fluctuation as people from the community are already immersed with the ecology where these mosquitoes thrive.

It is therefore important to note that the scientists and researchers are not the lone sources of information in order to come up with an effective and integrated vector management plan. A smooth and dynamic flow of communication among the key actors mentioned above (who should be all treated equally as source of information, **Figure 4**) will lead to the development of collective insights and informed decisions for the conceptualization, implementation, and actual application of innovative but cost-effective medical entomology research for the benefit of public health.

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