Innovations in the Entomological Surveillance of Vector-borne Diseases

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Edited by

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The people who assisted or supported us in the actual manuscript preparation and writing of this book include:

Writing and conceptualization: Adisak Bhumiratana and Evita Huerta Giusti

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Thanks also to the myriad of scholars and health personnel who have taken time to write about their projects, and without whom I would be clueless. Many of them are named in the Reference Sections of this book along with the titles of their influential work.

PREFACE

This book is about the techniques and methods that can be used to investigate, understand and manage human contact with those annoying biting creatures that spread disease. Such information is available, but not generally in a single book. Much of the information herein is presented with the intent of encouraging the development and implementation of efficient vector control and personal protection strategies that are appropriate and effective for various distinct local areas where a disease occurs with some regularity. That is to say, where the disease is endemic.

Even when they are not epidemic, vector-borne diseases are a stubborn public health problem in many countries. Despite advances in treatment and personal protection, vector-borne diseases manage to recur frequently, and sometimes outbreaks occur in unexpected places. Vector-borne diseases are not going away, but we have learned the principles and methods of epidemiological surveillance that can be applied to reconnaissance of currently crippling diseases like chikungunya, dengues, West Nile Virus etc. The concepts of vector surveillance may seem complicated because we are not focusing on a single disease, but we want to teach and discuss what we learned as we participated in the global efforts to eliminate malaria.

Although the term surveillance nowadays has a connotation of police monitoring, the word could be replaced with vigilance, observation, reconnaissance or simply investigation. At its root is the idea of survey (noun or verb: a general view, examination, or description of something). Public health surveillance is "the ongoing, systematic collection, analysis, and interpretation of health-related data essential to planning, implementation, and evaluation of public health practice", and generally refers to field investigations of populations at risk for disease. Surveillance for public health includes investigations of the carriers of diseases, including the arthropods and insects that transmit the infections.

While vector control efforts can reduce the populations of insects, surveillance is needed to discover when and where diseases are being spread. Worldwide, many of the innovations in surveillance target mosquitoes, particularly *anopheles* species that can transmit malaria parasites and *aedes* species that carry many virus species. We are also aware that innovations in vector control such as genetic manipulation will require a different sort of monitoring, and that not only the methods of surveillance, but the data we seek, will be changing. Similarly, innovations in disease treatment should augment but not degrade the importance of innovations in disease prevention.

Innovations are new or novel ways of doing things, often implying new technology, but also improvements in systems of work or business. Of course, innovative approaches are usually procedural modifications to help achieve some currently accepted standard, and do not necessarily imply that traditional or common procedures need to be abandoned. Our operating procedures are currently accepted because the outputs, if not the outcomes, are predictable, standardized and comparable.

If a disease is to be eliminated, systematic applications of epidemiology need to be developed which consider the entomological and ecological factors that contribute to the survival of the disease agent when it is not inside of humans. Hence, xenomonitoring, where "xeno" indicates something that is outside ourselves. Entomologic epidemiology attempts to discover which vectors are infected and where they transmit diseases to humans. Our approach to disease control considers variables of environment and ecology as well as specifics of the biology and behaviors of both the vectors and the victims.

RAM

EDITOR'S NOTES

The book is divided into four parts, each of which has chapters that present certain topics of interest to epidemiologists.

The first part of this book (theory) is to help you understand why entomological ecotopes are important to epidemiologist. There are diagrams!

The second part (practice) is about our investigations. It summarizes the research projects we have been involved in and which led us to create a comprehensive approach to tracking tropical vector-borne diseases. There are pictures!

The third part (methods) summarizes and explains modern tools available for entomologic surveillance and how to use epidemiologic methods for disease control and elimination. There are lists!

The seven chapters in Part three review the techniques and resulting measurements for each of the following foci of surveillance:

1.1 Human activities and risk behaviors
1.2 Entomological ecotopes: recognizing the carriers
1.3 Identifying and Mapping ecotope variables: Geographic Information Systems and other tools
1.4 Xenomonitoring: how to get data on pathogens outside of humans
1.5 Molecular analysis: identifying the pathogens
1.6 Quantifying and qualifying risk
1.7 Health literacy and communications

Part four (possibilities) presents a conjectural fusion of ideas that could be integrated into a potentially ideal system of disease surveillance. The intent is to initiate discussion of techniques and give examples for linking data and then suggest ideas for adapting, adopting and implementing these surveillance methods in novel environments.

Some of the most common vector-borne diseases and the vectors that cause them to spread are tabulated in the Appendices. But be aware that this book does not intend to address the medical diseases, the symptoms, or therapies. It does not even directly present the issues that surround the control of vectors. This book is about how to find and identify vectors, pathogens, and people at risk. It does that from a perspective of promoting public health, and considering variables which can be manipulated.

There are also indices, both by topic and alphabetical, along with samples of forms and work goals for you to develop, modify or translate for the purposes of investigating the vectors, pathogens and humans at risk in your territory.

PART 1

SPECIFICS OF VECTOR-BORNE DISEASE EPIDEMIOLOGY

INTRODUCTION

Infectious disease epidemiology focuses on tracking the infection and making maps of where the disease is occurring; then we implement an intervention to separate the humans from contact with the cause of the disease. You probably know of the various ways in which pathogens spread, commonly through touching, inhaling, or ingesting an active bacteria, fungi, virus, prion or parasite. The epidemiologist tries to find the source of the pathogen, and usually we find it came from another infected person, or a place polluted by other people, where it can survive.

However, some pathogens are *injected* into the humans by animal carriers called vectors. In general, the word *vector* means something that has a beginning point and a direction. In public health, we use the term vector when referring to living organisms that carry infectious diseases from an animal or human (where the pathogen comes from) to other humans (victims). Insect or arthropod vectors can transmit diseases among different animals (bats, rats, monkeys, birds, dogs, etc.) and humans. Vectors promote the existence of various microorganisms that survive across species. Many zoonotic diseases are also transmitted by insect and arthropod vectors. It is worth mentioning that often the transitional hosts (pathogen carriers) have no recognizable symptoms of infection. For example, you don't know whether rats, or the fleas that bite them, are carrying the plague bacteria *yersinia pestis*, but the infection will definitely affect humans that are bitten by fleas that have the bacteria in them. Figure 1 is a visual representation of the routes pathogens take to infect humans.

Vector-Borne Diseases are those that result from an infection transmitted to humans and other animals by blood-feeding arthropods, such as mosquitoes, ticks, and fleas. Examples of serious vector-borne diseases include Dengue fever, Zika, West Nile Virus, Lyme disease, malaria, chikungunya, Japanese encephalitis, yellow fever, leishmaniasis Chagas, etc. Treatment of these vector-borne diseases is rather difficult to implement in human populations. Typical problems in treatment include uncertain clinical diagnoses if the pathogen is in a dormant state when testing is done. There may be delayed onset of symptoms even if testing is positive, and sometimes infection may occur even after treatment. Contract tracing for cases is difficult because people cannot verify the time and place that infection occurred.

Vector-borne diseases create serious problems for *preventive public health*. The progression of vector-borne diseases among human populations is generally considered unpredictable. It has been difficult to prevent or control the spread of these diseases in humans, as outbreaks may occur despite treatment of cases or prophylactic treatment.

Epidemiology is the study and analysis of the distribution (who, when, and where), patterns and determinants of health and disease conditions in defined populations. The goal of public health epidemiologists is to discover the source of the pathogen or toxin, and neutralize its threat to humans. Detection of the source requires examination not only of the individual but also of the population in which the infection is spreading. Basic skills in epidemiology are those needed to track the course of the disease, usually by tracking symptomatic people, history taking and contact tracing to find out where the infection came from, mapping incident locations, collecting data on longitudinal events to see how the pathogenic infection is spreading over time, and projecting the routes of infection with the goal of creating an intervention to alter the spread of the disease in at-risk populations.

Most pathogens are transmissible, which means they can infect other susceptible beings. When the pathogens thrive and multiply, there is an infection which may cause disease. Some infectious diseases are communicable, and normally they are called contagious diseases.

Some commonly applied strategies that can limit the spread of disease pathogens are listed in Table 1. The tactics deployed should be chosen according to the characteristics of the disease.

Table 2 contains examples of activities that we can do to combat the spread of diseases. The reader should consider which tactics apply to any of the general strategies listed in Table 1.

Table 1 Communicable disease control (How to prevent spread of disease)

<u>**Intervention strategy**</u>	<u>**Objective**</u>
Sanitation	-healthy hosts = increased resistance -personal protection (clothing, condoms, repellants) -public and personal hygiene
Surveillance	-get data on incidence, location & sociodemographics of victims -sanitation inspections
Avoidance e.g.	-isolation -quarantine -evacuation
Resistance e.g.	-develop immunity -vaccines -exposure to related pathogens
Containment e.g.	-limit the area of infection -mass vaccination -ring vaccination
Control e.g.	-case management (treat sick people) -vector control -destroy the agent -render the agent harmless -destroy the hosts -culling (destroy potential hosts)

adapted from: *Communicable Disease Control In Emergencies: A field manual* Edited by M.A. Connolly WHO/CDS/2005.27 © World Health Organization, 2005, Connolly, Máire A. ISBN 92 4 154616 6 (NLM Classification: WA 110) Available as PDF on the internet

Table 2: Sample Interventions for disease prevention

- Close schools to prevent spread of disease
- Avoid exposure to toxins e.g. no smoking
- Drink non-alcoholic beer or wine
- General hygiene measures
- Ensure proper food handling and storage
- Inspect personal hygiene.
- Promote healthy child development
- Provide required medications
- General cough etiquette and hand-washing
- Medical follow up of symptoms
- Reporting
- Track infections more accurately
- Control rodents and insects
- Keep animal enclosures clean and dispose of dead birds
- Clean and disinfect the facilities
- Enforce laws and regulations to prevent spread of disease
- Reduce contact with animals
- Create rapid diagnostic testing programs
- Develop and distribute vaccines
- Control the use of antibiotics
- Control antimicrobial resistance
- Developing mitigation strategies
- Decontamination

Note: A list of how to organize interventions for outbreaks of specific diseases can be found in the book *Communicable Disease Control in Emergencies: A field manual* Edited by M.A. Connolly WHO/CDS/2005

The tactics for preventing the spread of the disease should be in accordance with the objectives seen in Table 1. While vector-borne disease epidemiology shares some (maybe many) features with general disease epidemiology, those unique features cannot be ignored. This would be a good place to point out that the steps to prevent the spread of COVID-19: social distance, masks and handwashing are irrelevant to vector borne disease. Three basic methods of avoiding vector-borne disease are to limit exposure of humans, control or contain the vectors, and importantly, to understand and manage the environment.

Sometimes the intervention activities require enforcement of laws and regulations to prevent the spread of disease. Many of our regulations of animals exist because we have learned that zoonotic infections can be acquired by humans as well. Sometimes the purposes of regulations are not directly apparent, such as policies about spraying for insects or prohibiting pools of standing water (for instance in a garbage bin), which may relate to preventing the spread of bacteria or the reproduction of mosquitoes and flies that carry disease. Figure 1 illustrates how epidemiologists visualize the path of a pathogen, and you can use it when deciding which part of the chain to target for blocking or destroying the thing that is causing infection.

Three factors are considered in any *epidemiological analysis*, i.e. Agent, Host, and Environment. However, vector-borne disease epidemiologists also need to collect evidence regarding the pathogens (agents) when they are not in humans; this is called *xenomonitoring*.

1. Agents are the disease-causing pathogens and they are transmissible via vectors. Medical epidemiologists tend to focus on the characteristics of the pathogenic agents, which may be parasites, bacteria, or viruses. Often medical epidemiologists are pathologists who are trained to identify the infectious agent that is isolated from patients. However, in studying the spread of disease, we must also consider other environments in which a pathogenic agent can survive. Vector-borne diseases can obviously survive inside of various species, and some survive and thrive even outside of hosts.

2. Hosts can be any human or animal with the pathogen in or on it. It is important to note that there may be intermediate hosts of pathogens; that is animals or insects, and they may or may not show signs of distress.

3. Environment is the conditions under which an organism can stay alive. It is important to recognize that the pathogen needs an environment, as do the hosts of that pathogen. Our research however, focused on the vectors, which also thrive in specific environments. Much of this book is about how to describe the physical environments where hosts, agents and vectors come together. (see Figure 2)

Vector-borne disease epidemiology encompasses the theory of chain of infection but the analysis is complicated because the disease life cycles, both intrinsic (in hosts) and extrinsic (outside of hosts), need to be considered to understand how the pathogenic agents such as parasites and arboviruses can be transmitted. Not only are the above tasks required, but the epidemiologist needs to be aware of the vector populations, their locations and characteristics (entomology), as well as the situations that expose people to an untraceable pathogen which originates from an unknown source (anthropology). The concepts that need to be integrated into the descriptive and analytical epidemiological models, including the agent – host – vector interactions in a particular environment are pictured in Figure 2.

Disease outbreaks occur when vectors transmit the disease at a large scale in short time. Unlike infectious diseases that require human-to-human contact, tracing an index case (patient 0) and the source or progression of the pathogen is complicated by the varied incubation periods of the pathogen in vectors, in possible intermediate hosts and in the human patient. The elimination of the vector is normally the best way to address elimination of the disease. However, the disease-carrying insects are deeply rooted in the environment where they prevail. Many of the vector-borne diseases are *endemic* in tropical regions, where insects are ubiquitous throughout the year.

Normally, people are not aware of which arthropod is the vector of a particular disease. For example, Scrub Typhus is not carried by common ticks, but can be spread by chiggers. Professionals and people at risk do not know which mosquitoes carry which disease. Sandflies and no-seeums are pests that may be ignored, but which may carry some diseases. In order to explain how the efforts of vector-borne disease epidemiologist can be applied to rapid intervention, and possibly prevention or even elimination of disease, we use the visualization shown in figure 2.

In figure 2 the overlaps show the influence of variables that determine the patterns of a vector-borne disease. The ideas of fitness and selection are difficult to quantify, therefore no universally useful model has been developed for forecasting.

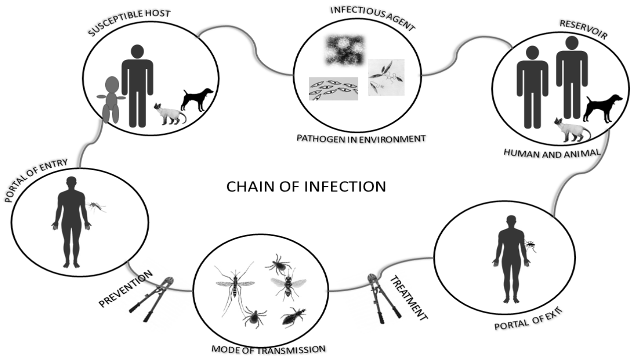

Figure 1: A chain of infection concept for Vector-borne disease

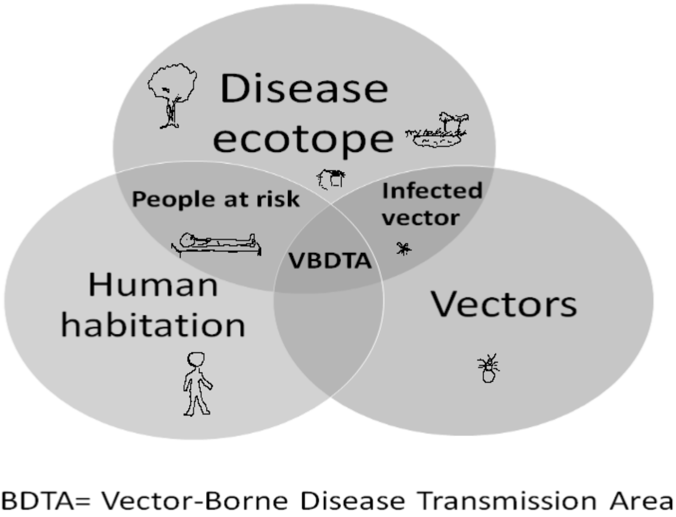

Figure 2: Components of a vector-borne disease transmission area, aka hot spot

This Venn diagram is to clarify that, although the insects may be ubiquitous, there must be an environment that supports the disease agent (for example malaria) including when present in the hosts (including mosquitoes) and that people must also be in that environment. Entomologic and ecotopic surveillance is needed to define the specific environmental factors (ecotopes) in which the vector mosquitoes can survive and bite people. Those places would be represented by the overlapping areas in the middle of this diagram.

CHAPTER ONE

ENVIRONMENTS OF PATHOGENS, CARRIERS AND HUMAN VICTIMS

RONALD MARKWARDT,
PRAPA SOROSJINDA NUNTHAWARASILP

For vector-borne diseases, the pathogen is mobile and often hidden. However, despite the dispersion of human victims, it has long been observed that certain geographical areas or environments promote and support particular diseases.

Understanding Endemicity (Malaria example)

For example, the maps in figure 1.1 below are typical of the data available for incidence of malaria in Thailand. When one looks at the map of incidence or prevalence of malaria in Thailand, we see that malaria is reported in the provinces that are at Thai-borders, but certain other regions are unaffected.

Accumulated data of the type used to produce the maps in figure 1.1 gives us a broad picture of the disease situation, but provides little information for those who need to apply preventive interventions that will stop the disease from spreading. The *local data* that would explain disease transmission is lost in the process of summarizing and reporting.

Current prevention initiatives being promoted by the WHO and other NGO's are moving from a blanket approach toward a more targeted approach to eliminate malaria in local areas and environments. Some literature calls these areas "disease endemic areas" or "hotspots". If local data is analyzed independently of the combined data, it should allow us to create customized, targeted interventions for disease prevention. Cases of human malaria might be spreading in only a small district or village, or even specific farms. It is not the whole population of the province that is at risk, and interventions such as vector control may not need to be carried out in the whole province. Diligent surveillance[1] is the technique that has been adapted to help target malaria interventions by programs such as Roll Back Malaria [2005]. As progress is made against malaria and other mosquito borne diseases, new and more efficient surveillance techniques need to be applied.

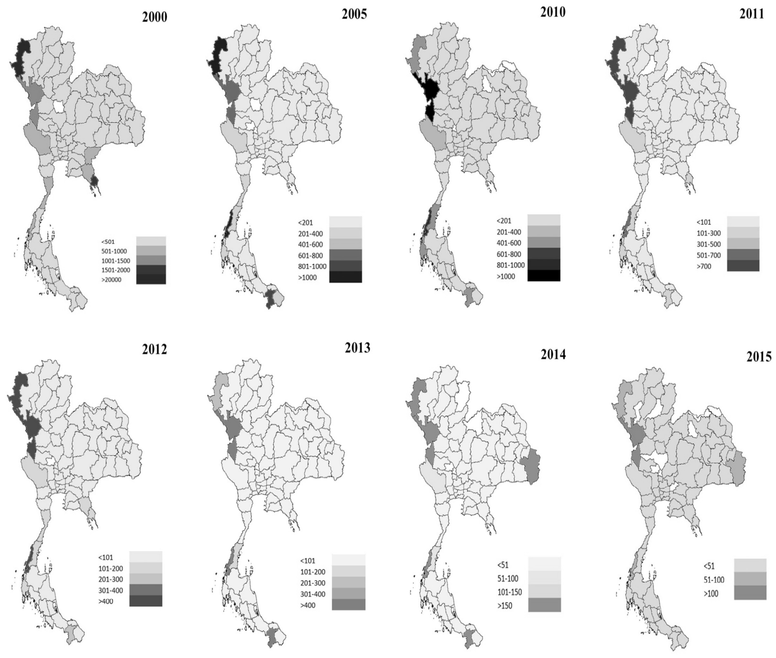

Figure 1.1 Several years of malaria prevalence data for provinces of Thailand. (The maps above are created by Thanaporn Nunthawarasilp with data from the National Ministry of Public Health, Thailand).

Transmission patterns of vector-borne pathogens

In vector-borne disease, the exposure is a bite by a common insect. Our task then in preventing disease is to discover which of the insect vectors are infected. Meanwhile, we target our efforts at preventing exposure to the carrier species. The transmission of disease by vectors can be classified

[1] Some diseases are of sylvatic origin, meaning that wild animals are infected with, or hosts of, the pathogen.