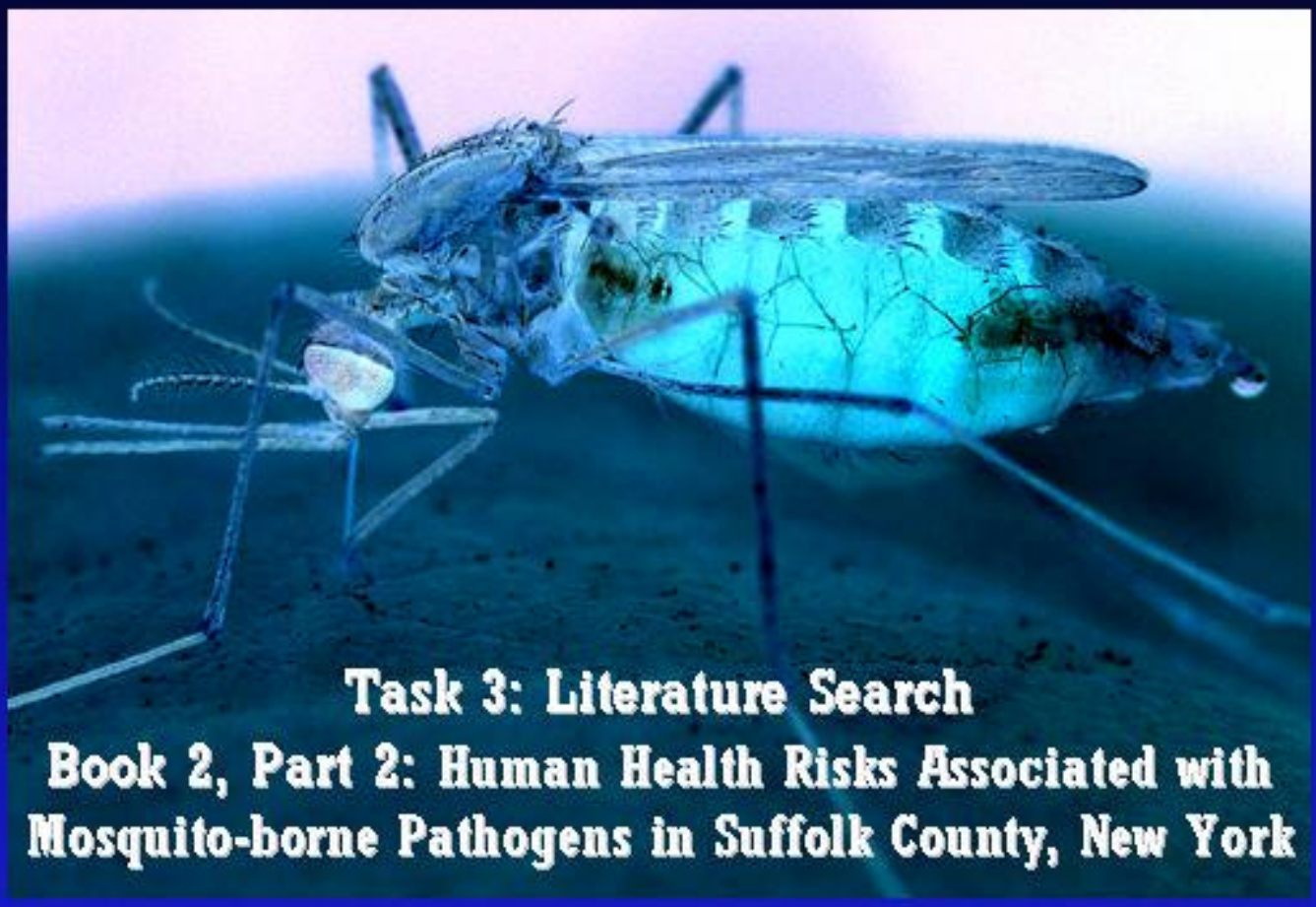
Suffolk County Vector Control & Wetlands Management Long Term Plan & Environmental Impact Statement



Task 3: Literature Search
Book 2, Part 2: Human Health Risks Associated with Mosquito-borne Pathogens in Suffolk County, New York

Prepared for:

Suffolk County Department of Public Works
Suffolk County Department of Health Services
Suffolk County, New York

Prepared by:

CASHIN ASSOCIATES, P.C.
1200 Veterans Memorial Highway, Hauppauge, NY

September 2005

SUFFOLK COUNTY VECTOR CONTROL AND WETLANDS MANAGEMENT LONG - TERM PLAN AND ENVIRONMENTAL IMPACT STATEMENT

PROJECT SPONSOR

Steve Levy
Suffolk County Executive

Department of Public Works
Charles J. Bartha, P.E.
Commissioner
Richard LaValle, P.E.
Chief Deputy Commissioner
Leslie A. Mitchel
Deputy Commissioner

Department of Health Services
Brian L. Harper, M.D., M.P.H.
Commissioner
Vito Minei, P.E.
Director, Division of Environmental Quality

PROJECT MANAGEMENT

Project Manager: Walter Dawydiak, P.E., J.D.
Chief Engineer, Division of Environmental Quality, Suffolk County Department of Health Services

Suffolk County Department of Public Works, Division of Vector Control
Dominick V. Ninivaggi
Superintendent
Tom Iwanejko
Entomologist
Mary E. Dempsey
Biologist

Suffolk County Department of Health Services, Office of Ecology
Martin Trent
Acting Chief
Kim Shaw
Bureau Supervisor
Robert M. Waters
Bureau Supervisor
Laura Bavaro
Senior Environmental Analyst
Erin Duffy
Environmental Analyst
Phil DeBlasi
Environmental Analyst
Jeanine Schlosser
Principal Clerk

SUFFOLK COUNTY LONG TERM PLAN CONSULTANT TEAM

Cashin Associates, P.C.	**Hauppauge, NY**
Subconsultants	
Cameron Engineering, L.L.P.	Syosset, NY
Integral Consulting	Annapolis, MD
Bowne Management Systems, Inc.	Mineola, NY
Kamazima Lwiza, PhD	Stony Brook University, Stony Brook, NY
Ducks Unlimited	Stony Brook, NY
Steven Goodbred, PhD & Laboratory	Stony Brook University, Stony Brook, NY
RTP Environmental	Westbury, NY
Sinnreich, Safar & Kosakoff	Central Islip, NY
Bruce Brownawell, PhD & Laboratory	Stony Brook University, Stony Brook, NY
Anne McElroy, PhD & Laboratory	Stony Brook University, Stony Brook, NY
Andrew Spielman, PhD	Harvard School of Public Health, Boston, MA
Richard Pollack, PhD	Harvard School of Public Health, Boston, MA
Wayne Crans, PhD	Rutgers University, New Brunswick, NJ
Susan Teitelbaum, PhD	Mount Sinai School of Medicine, NY
Zawicki Vector Management Consultants	Freehold, NJ
Michael Bottini, Turtle Researcher	East Hampton, NY
Robert Turner, PhD & Laboratory	Southampton College, NY
Christopher Gobler, PhD & Laboratory	Southampton College, NY
Jerome Goddard, PhD	Mississippi Department of Health, Jackson, MS
Sergio Sanudo, PhD & Laboratory	Stony Brook University, Stony Brook, NY
Suffolk County Department of Health Services, Division of Environmental Quality	Hauppauge, NY

Primary research for this report was conducted by Harvard School of Public Health (personnel including Andrew Spielman, Masahiko Hachiya, and Richard J. Pollack). It was edited and revised in response to comments by Cashin Associates (personnel including Elyse O'Brien and David Tonjes, PhD). Review was provided by Suffolk County Department of Public Works, Division of Vector Control, and Suffolk County Department of Health Services. Additional comments have been received from _____.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS AND ACRONYMS

BRN	basic reproduction number
EEE	Eastern equine encephalitis
CDC	Centers for Disease Control and Prevention
MFIR	minimum field infection rate
WNV	West Nile virus

Executive Summary

This analysis of the potential for the transmission of mosquito-borne infection in Suffolk County examines the forces that determine risk of infection and the efficacy of the existing abatement efforts that are practiced there. Vector-borne infections tend to arise explosively, affecting large segments of the resident population. They are linked to environmental degradation and to the importation of novel pathogens, vectors, or reservoir hosts.

The recent outbreak of West Nile Virus (WNV) infection in Suffolk County (and elsewhere in the region) spanned the years 2000 through 2003 and waned in 2004. Regionally, transmission intensity has remained level or risen during July and into September of 2005. Although fewer than two dozen residents of Suffolk County have suffered clinical disease from WNV, it is particularly pernicious because it strikes where people feel most secure, in their homes and in urban and suburban sites. Everyone feels vulnerable; but the burden falls most heavily on the elderly. Abatement efforts may have reduced risk of human infection in Suffolk County.

Diverse kinds of mosquitoes may acquire and transmit WNV in nature. Although the enzootic vector in this region, *Culex pipiens*, feeds mainly upon birds, some proportion of these mosquitoes feed on mammals, particularly during late summer and early fall. Thus, these mosquitoes, when infectious, can pose direct risk to people. Abatement efforts against this mosquito may moderate the amplification of WNV in nature, and may limit exposure of people to such infected mosquitoes.

The salt marsh mosquito, *Ochlerotatus sollicitans*, is a major nuisance to the residents along the Atlantic-facing coast of Suffolk County. Because of its abundance, relatively indiscriminate choice of hosts (feeding on birds and mammals), penchant for attacking people, and competence as a vector for arboviruses, it may also serve as a bridge vector of virus from birds to other hosts, including people. Abatement efforts, which have long been directed against this particular mosquito, may reduce risk of human infection in Suffolk County.

Risk of acquiring Eastern Equine Encephalitis (EEE) may have increased in recent years, due, possibly, to the return of wetland forest within the County. EEE infection is often fatal. The burdensome sequellae in those who survive infection may cost society, on average, several millions of dollars. The salt marsh mosquito has occasionally been found to carry this pathogen;

thus, it may serve as a bridge vector to transfer EEE from its sylvan cycle to human hosts. Certain abatement measures that may help reduce risk of one of these infections would do so for the other.

Various other mosquito-borne pathogens may become established in North America, and Sindbis virus seems to be a prime candidate for such an event. Its cycle is similar to that of WNV. Its potential for invasion is illustrated by a recent outbreak in Scandinavia.

A tick-borne infection, due to the agent of Lyme disease, which was introduced into Suffolk County during the mid-1900s, stands as an example of the burden that such an infection can impose on a human population.

The mosquito abatement activities that have long been practiced in Suffolk County are consistent with those generally accepted and utilized by those within the public health and vector management community to diminish nuisance caused by mosquitoes as well as to limit risk of vector-borne infection. Evaluating the extent to which these efforts are effective, however, is a difficult and controversial process. We encourage public health and vector management officials in Suffolk County to further optimize their surveillance and intervention activities as conditions warrant and as resources allow.

1. Introduction

1.1. Mosquito-Borne Disease

Mosquitoes transmit numerous infections that powerfully threaten human health. The burden of these infections is heaviest in West Africa, where malaria severely constrains human activities. Rudyard Kipling wrote of the "Bight of Benin, where many go out, but few come in." The writings of such 19th Century travelers as du Chailu and Kingsley described the mortal dangers that await visitors to the region (malaria continues to be transmitted intensely there). Visitors generally notice few mosquitoes; but before quinine became readily available, malaria is said to have claimed between five to ten percent of English visitors to the region annually. Indigenous adults, however, live apparently normal lives because their malaria infections are modulated by acquired immunity. Young children are particularly vulnerable because disease-modifying immunity develops slowly. Those that survive to later childhood become immune but continue to be infected by this chronic, but well tolerated infection. The development of potent anti-malaria drugs during the mid-20th Century provided a temporary respite from this infection. Beginning in the 1980s, however, the various synthetic drugs increasingly lost their anti-malaria efficacy, and malaria began to claim the lives of visitors as well as long-term residents in the Bight of Benin, especially children and pregnant women. The advent of the 21st Century, therefore, brings with it something of the character of the 1800s. Quinine is, once again, becoming the drug of choice there, and visitors must adopt increasingly burdensome precautions against malaria. The situation has deteriorated. The future of West Africa, therefore, seems bleak, even if other potent health threats, such as AIDS, were to be addressed. Currently, malaria incidence in the "Bight of Benin" approaches 100 percent of the resident population there.

This extreme example of the burden that mosquito-borne infection may impose on a region illustrates certain peculiar features of these diseases that differentiate them from the more directly transmitted infections (Spielman and Rossignol, 1984). Most basic is the tendency of mosquito-borne infections to cluster spatially because their vectors depend on particular features of the environment. Individual risk of infection may vary, even between nearby dwellings. Another peculiar feature of such infections is their tendency to affect large numbers of people in a relatively brief period of time. Outbreaks frequently are explosive because a mosquito can

carry the pathogen beyond the direct contacts of the originally infected host. In addition, such infections tend to be silent in their natural cycles because pathogenesis correlates with age and immunity modulates the expression of symptoms. Finally, the intensity of transmission depends far more on intrinsic properties of the vector mosquitoes than on their abundance. Mosquito-borne infections, therefore, tend to be peculiarly burdensome because they may so suddenly and severely affect many residents of a site even in the apparent absence of the mosquitoes that are transmitting the infection.

A diverse array of mosquito-borne infections threatens the residents of Suffolk County, including certain "endemic" pathogens that have long been transmitted there. Other infections may be "imported" by travelers who encountered them elsewhere and may become ill after their return, or the infectious agents may accompany an exotic vector or vertebrate host arriving naturally or facilitated by transport on or in vehicles and cargo (Pollack and Marcus, 2005). Such imported infections generally are not subsequently transmissible on Long Island. Other infections are said to be "introduced" when environmental conditions permit transmission of one or more secondary cases. The term "perpetuating" is applied to such an introduction when each case, on average, gives rise to at least one secondary case. Epidemiologists apply the term "basic reproduction number" or "BRN" to this property of an infection (Anderson and May, 1991). Measles, one of the most transmissible of the directly transmitted infections, is said to have a BRN of about 14. That of malaria, on the other hand, generally exceeds 100 and may even approach 1000 around the Bight of Benin. Outbreaks of mosquito-borne infections, in general, are far more explosive than are directly transmissible infections.

The life cycles of mosquito-borne infections frequently are complex, involving diverse kinds of hosts. Animals are said to serve as "reservoir hosts" in the event that they support a sufficient level of infection that some mosquitoes become infected when they imbibe their blood (Spielman and Rossignol, 1984). Those mosquitoes that subsequently infect some reservoir hosts are said to be "vectors." Reservoir hosts, as the name implies, wait passively until some vector mosquito is attracted to their bodies. As in mathematics, a vector serves as a "force with direction," a property that accounts for the exceptional level of transmissibility of vector-borne infection. In the event that a pathogen infects some combination of reservoir and vector hosts such that its BRN exceeds one, the cycle is designated as a "maintenance" cycle. These mosquitoes are said

to be "maintenance or enzootic vectors." Transmission is said to be "vertical" when the pathogen passes directly from an original host to its progeny, while "horizontal" implies that prevalence of infection is amplified within a generation by transmission between hosts. The term "bridge or epidemic vector" is applied to those mosquitoes that become infected after imbibing the blood of a reservoir host and are capable of infecting a person but fail to infect sufficient reservoir hosts that the infection perpetuates itself. Bridge vectors tend to feed indiscriminately. An infection is said to be "anthroponotic" in the event that it perpetuates in a human reservoir of infection and "zoonotic" when some non-human host serves to perpetuate infection. Because they exploit different larval developmental habitats, intervention strategies directed against bridge vectors may differ from those that focus on maintenance vectors.

Risk of human infection by a mosquito-transmitted pathogen generally is phrased in terms of the degree of exposure to infected vector mosquitoes. This convention, "entomological inoculation rate," is the product of an estimate of the frequency of biting by a particular kind of mosquito and the prevalence of infection in those mosquitoes. In the case of a zoonosis, prevalence of such infection in a maintenance vector generally exceeds that in a bridge vector. Frequency of biting a person by a bridge vector, however, tends to be much greater than by a maintenance vector.

Prevalence of infection in a vector usually is expressed as a "minimum field infection rate," or "MFIR." This calculated value assumes that in any "pool" (group of individuals) of mosquitoes assayed and found with evidence of infection, just one individual was likely infected. The MFIR is a means to standardize results when pool sizes differ, by expressing the data as the minimum number of infected mosquitoes expected in any group of 1,000 sampled at the same time and place. The MFIR offers a snapshot of infection prevalence in time and place for one kind of mosquito, and is most useful when coupled with other kinds of data for comparing results temporally from one site, or from concurrent pools sampled from different sites.

MFIR statistics tend to underestimate prevalence when a pool contains more than one infected mosquito. Conversely, by assuming that each infected mosquito may be infectious, MFIR may overestimate risk.

In general, mosquitoes do not inherit infection. Instead, they must ingest viable viruses circulating in the blood stream of an infected reservoir host. Once within the gut of a competent mosquito, the viruses must enter certain cells of the mosquito, replicate there, then translocate to mosquito's salivary glands. The virus may be detectable, by laboratory assay, within the body of a mosquito at any interval from the moment it has ingested virus; such a virus-containing mosquito is considered "infected." The mosquito is not able to transmit that infectious agent, however, unless and until the virus has attained position within the mosquito's salivary ducts. Once there, virus will be flushed into a new host's skin as the mosquito inserts her proboscis to probe and feed. The interval until transmission is possible from ingestion is termed the extrinsic incubation period. The duration of this interval is dependent upon the kind of mosquito and virus, as well as the ambient temperature. Generally, the extrinsic incubation period extends to one or more weeks. During this interval, the mosquito must survive and she may have several opportunities to blood feed. Risk of transmitted infection, then, is mainly a function of the mosquito's age. Whereas the age of the mosquito is a critical attribute, it is a difficult characteristic to ascertain. Currently, it is impractical to assay the age of more than a small sample of mosquitoes.

MFIR statistics, by themselves, are relatively irrelevant unless paired with data pertaining to the abundance of the associated vectors. The product of these linked values becomes more meaningful when considered in context with the host preferences of the vector, the abundance of reservoir hosts and of people, and the prevalence of infection in reservoir hosts. Direct observations or objective measurements of each of these components are exceedingly difficult, and often completely impractical. Consequently, estimates of risk, generally, are based upon limited measurements of mosquito abundance and infection prevalence.

Results of mosquito surveillance trapping tend to underestimate risk to the community. The best available traps poorly sample many kinds of mosquitoes that may be impressively abundant and frequently attack people. At best, arrays of surveillance traps offer a valuable but exceedingly narrow sample of the diversity and abundance of mosquitoes, and of the dynamics of pathogen transmission. Mosquito traps in Suffolk County have been deployed to monitor populations of human-biting mosquitoes, and to provide samples of potential vectors for arbovirus assays by the New York State Department of Health. The kinds of traps utilized, and their placement

throughout the county, reflect careful consideration of the ecology of each of the main vectors in the region, the epidemiology of the main vector-borne infections, the density and distribution of residents throughout the county, and the ability of the county agencies to perform meaningful interventions. The objective data provided by these surveillance efforts are considered collectively with those relating to virus prevalence in assayed mosquitoes and vertebrates, the distribution of dead birds reported to the health agency, and the temporal and spatial dynamics of reports from residents complaining about mosquito annoyance.

Meaningful attempts to quantify and model risk for any community, and to assess the effects of interventions, require robust data relating to each of the components described above. The vector management and public health agencies in Suffolk County collect and record an impressive body of pertinent data useful for driving their daily operational efforts. Their efforts, and the structure of the data they collect, however, neither have been designed to directly assign site- and time-specific risk indices nor evaluate the efficacy of their interventions. Efforts to address these issues would require a reevaluation of the goals and operational structure of these agencies. The strategies employed by the county agencies tasked with vector management and public health are those that are widely accepted and applied elsewhere, and for which most experts in the vector biology and management community believe offer far more benefit than risk.

The intensity of transmission of these mosquito-borne pathogens tends to wax and wane. Viral pathogens are particularly variable because immunity is sterilizing, and the prevalence of immunity in the reservoir population strongly modulates transmission intensity. This affects mosquito-transmitted viruses more than those that are directly transmitted because vector mosquitoes attack reservoir hosts at intervals of several days or more. The number of hosts that each such mosquito can contact, therefore, is finite. If only two bites are taken, and one is "wasted" on an immune host, the other is similarly lost to the transmission cycle.

1.2 Ecology of Suffolk County

Long Island emerged from beneath its mile-thick blanket of ice 15,000 to 20,000 years ago. Its environment has evolved drastically (Cronon, 1983; Black, 1996). When Verrazano viewed the Rhode Island shore in 1583 he noted in his log that the landscape was so open that he could

march an army across the region without their breaking step. Stately groves of white pine or of chestnut punctuated vast meadows covered by tall grass. Brush was present solely in wetland sites, where it could not be burnt. The pre-Columbian residents of North America maintained this landscape by burning whatever brush and downed wood could be burnt. The Pilgrims in 1619 simply planted their wheat in the fields that had previously been devoted to maize. Their vista is said to have been magnificent.

Thoreau described the last stages of the desecration of this idyllic environment. The railroads were then, in 1835, encroaching on his Walden home, and the last remaining trees were being converted into ties and fuel for its locomotives (Foster, 2003). The appetite for charcoal for cooking and for the burgeoning iron and glass industries was insatiable. The region was being defaunated. Deer, bison and elk had long ago been converted into material that could be bartered for iron. Passenger pigeons would soon become extinct. Thoreau noted that he knew an elderly woman who, in her youth, knew a man who had seen a deer. By 1900, much of Long Island similarly was stripped of its forest cover and had lost much of its vertebrate fauna. European grasses that could withstand trampling by the hoofs of cattle replaced the native grasses, and various exotic trees and other plants had been introduced. House sparrows and European starlings were introduced deliberately into nearby Westchester County. House mosquitoes, *Culex pipiens*, which had been introduced from Africa on sailing ships, began to thrive in the urban centers that were then developing.

A novel forest began to develop on Long Island after the arrival of European immigrants in the New World (Black, 1996). The pine barrens that came to dominate the region initially developed in response to selective removal of hardwoods. "By 1812, Brookhaven Town alone was estimated to be sending 100,000 cords of wood to [New York] City annually." By 1844, the New York to Boston Railroad was largely responsible for the many fires that dominated the region and the fire-dominated landscape that perpetuated these pine barrens. More recently, the landscape became dominated by crowded saplings interspersed with brush. As these trees aged, many branches broke from their trunks and littered the ground. In the absence of fire, dead trees remained in place, creating a jumbled landscape that was amenable to deer, raccoons and opossums. The wetland forests began to return. Older trees are located mainly along roads or on farmsteads.

Proliferation of certain faunal elements of public health importance accompanied these landscape changes. The relevance of each of these organisms will be discussed in the following text. The abundance and proximity of two exotic creatures, house sparrows and of house mosquitoes, seems to have prepared the region for the maintenance of WNV. The local abundance of starlings (also exotic) and of swamp mosquitoes potentiated transmission of EEE. Similarly, the burgeoning deer population potentiated transmission of Lyme disease and its co-infecting tick borne pathogens as well as the mosquito-transmitted Cache Valley virus and of Jamestown Canyon virus. The maturation of trees permitted water-filled rot-holes to develop, in which the vectors of La Crosse virus could develop. The trade in used automobile tires permitted the introduction of certain Asian mosquitoes that avidly feed on people and that may serve as vectors for certain human pathogens.

1.3 Disappearance of malaria and yellow fever from North America

Mosquito-borne infection, at the turn of the last century, was very much part of life in the United States. Malaria severely debilitated people throughout the region, extending well into southern Canada. Hundreds of the residents of particular sites might acquire infection, and the Tennessee Valley Authority region was particularly vulnerable. In the wake of the Great Depression, President Roosevelt sponsored programs for the unemployed that were designed to reduce the force of transmission. Installation of screen doors was an important feature of this effort, such that the repeated "banging" that they produced as children entered and left their homes became the signature sound of the rural south. Although DDT became available for anti-malaria use soon after the end of World War II, malaria had disappeared before large-scale efforts could be implemented. Simple home improvement had prevented sufficient anopheline contact with people that transmission was destabilized.

Yellow fever was another notorious curse. One city after another was rendered virtually uninhabitable due to this dreaded disease. Most notorious were the outbreaks that struck Philadelphia in 1790's, at the time of the Continental Congress (Murphey, 2003; Barrett and Monath, 2003). Thomas Jefferson's writing of the Constitution was inhibited, and George Washington delayed his visit to this capital city. Such episodes of disease resulted from water storage within houses, and centralized water supplies signaled the end of these infections, transmitted by the exotic *Aedes aegypti* mosquito. Air conditioning and television, by inhibiting

contact between people and mosquitoes, now further ensure against a repetition of such outbreaks of these diseases here.

2. Mosquito-associated diseases of concern in Suffolk County

2.1. Overview

A surprisingly diverse array of mosquito-borne pathogens may infect the human residents of Long Island. These include infections that are endemic, others that are imported, and some that have been introduced. Many of these pathogens are arboviral in nature; a term representing a contraction of "arthropod," "borne," and "virus." The environmental requirements of many exotic arboviruses would, indeed, be compatible with the indigenous mosquitoes, birds, and mammals of the northeastern United States. The diversity of those that are present in western Europe (Lundstrom, 1999) include many that might someday be introduced onto Long Island or already perpetuate there. They include viral agents in the family Alphaviridae, Flaviviridae, and Bunyaviridae. Certain of these viruses are transmitted by aedine mosquitoes, and others by culicine or anopheline mosquitoes. Some arboviruses perpetuate in mammals and others in avian reservoir hosts. They include WNV, the various "equine" encephalomyelitis viruses (Eastern, Western), La Crosse virus, Sindbis virus, Tahnya virus, Inkoo virus, Batai virus, Lednice virus, Usutu virus and Semliki forest virus. Many are neurotropic. Among others, Australia plays host to Murray Valley encephalitis virus, Kunjin virus, Alfuy virus, Kokobera virus, Ross River virus, Barmah Forest virus, and Sindbis virus. When South America, Africa, Asia, and Oceania are considered, the list of potential introductions grows to daunting proportions.

The need for a pre-existing system for combating an arboviral introduction was demonstrated by the failure of New York City to deal adequately with the outbreak of WNV that occurred in 1999 (Komar, 2004). Although a mosquito abatement organization had been established there in 1901, its operations ceased after 1956 (Miller, 2001). Equipment and skilled personnel had to be borrowed from the city's neighbors, including Suffolk County and the Centers for Disease Control and Prevention (CDC), and hired from distant contractors.

2.2. An emerging introduced pathogen

2.2.1. West Nile virus

WNV first appeared in the Americas, in the shadow of LaGuardia Airport, during the summer of 1999. The outbreak became evident when an alert physician noticed similar symptoms in two elderly patients in Flushing Hospital. They were experiencing simultaneous episodes of a

peculiar flaccid paralysis and encephalitis (Asnis et al., 2000). She notified the New York City epidemiologist, and joined with her in a successful attempt to unravel the circumstances surrounding this strange coincidence. A veterinary pathologist working at the Bronx Zoo (T. McNamara) had noted a somewhat similar syndrome in crows and certain zoo animals earlier that year.

WNV first was identified in the blood of a resident of Uganda who was experiencing a febrile episode (Smithburn et al., 1940), and its neuropathologic potential described in Israel in 1957 (Spigland et al., 1958). A massive outbreak, affecting some 10,000 people, struck South Africa in 1974 (Jupp, 2001), and another in 1996 caused 393 clinical episodes with 16 deaths in Romania in 1996 (Tsai et al., 1998). The Volgograd region of Russia experienced a similarly widespread outbreak (Platinoff et al., 2001). Although no human disease is evident in the United Kingdom, many British birds seem to have been infected (Buckley et al., 2003). A particularly virulent variant of WNV was isolated from a goose in the Jordan Valley of Israel in 1998 (Malkinson and Benet, 1999), the year before the virtually identical virus was discovered in a crow that had died in New York City. The range of this virus has increased progressively, striking Canada in 2002 and the West Coast of North America in 2004. Many thousands of lives have been affected. The recent experience in Israel, for example, illustrates this element in the force of WNV transmission (Table 1). Human cases tend to be most frequent during the first year or so of the outbreak and to disappear after a few years, only to reappear some years later. Outbreaks tend to wax and wane.

Year	No. human cases (Israel)	No. deaths
1999	0	-
2000	430	29
2001	37	2
2002	7	1
2003	3	0
2004	0	-

Table 1. Recent experience with WNV in Israel (Data reported by the Ministry of Health of Israel).

The epidemic curve for human WNV disease in the northeastern US differs from that in the south and the west, where other vectors are involved. Cases are diagnosed most frequently

during September (Figure 1), about a month after reproductively active house mosquitoes have become most abundant (Figure 2). This month-long gap separating vector abundance from disease onset cannot fully be explained by the duration of incubation of the virus in avian and insect hosts, which would total about two weeks. An additional explanation lies in the manner in which the mean age of these mosquitoes increases throughout the August and September that follows their emergence (Figure 3). Because an increasing proportion of these surviving mosquitoes have already taken one or more meals of blood, they become increasingly dangerous. Their probability of WNV infection in these mosquitoes progressively increases as does the likelihood that they will feed on a human host. Older mosquitoes become increasingly indiscriminate in their choice of hosts (Spielman, 2001). A diverse array of clinical manifestations characterizes WNV infection in people (Komar, 2004). The vast majority of human infections, however, are silent; only about one in a hundred infected people become symptomatic (Poshni et al., 2001). Pathogenesis is age-related, with neurologic complications affecting as many as half of patients more than 50 years of age. Extreme muscle weakness, eye abnormalities, and coma may be experienced, and death may result. Younger patients generally experience fever, a diffuse rash, fatigue, malaise, and gastrointestinal symptoms.

WNV perpetuates on Long Island in a cycle involving house mosquitoes as maintenance vectors. Some 23 times as many of these mosquitoes feed on birds than on other animals (Apperson et al., 2002). They readily become infected and are capable of transmitting the virus after a few days (Turell et al., 2001). This focused avian feeding pattern combines with their virus competence to rank these mosquitoes as the chief maintenance vector of WNV in the northeastern US. House mosquitoes breed in the accumulations of foul water that are so common near houses, as in street drains (catch basins), abandoned wading pools, leaf-lined puddles, and clogged roof gutters and down-spouts. They reach maximum abundance during mid-August (Spielman, 2001; and Figure 2). Subsequently, any newly emergent house mosquitoes feed solely on sugar and accumulate fat instead of forming eggs, and seek shelter for hibernation rather than hosts for blood. Such mosquitoes contribute to the transmission cycle only some nine months later and not during the weeks immediately following their emergence.

House sparrows are the chief maintenance reservoirs of WNV in the northeastern US. The abundance of these birds is at least six times as great as that of any other bird on Long Island

(pigeons). They are infected at least twice as frequently (Komar et al., 2001). As their names imply, the ecological niche occupied by house sparrows corresponds closely to that occupied by house mosquitoes. House sparrows roost communally in urban sites, and many such birds accumulate there beginning in August, after the young birds have fledged. House mosquitoes feed mainly near the tops of trees (Anderson et al., 2004). This conjunction of massed house sparrows and house mosquitoes in space and time provides the logical venue of WNV transmission.

The intensity of transmission of WNV in Suffolk County reflects the pattern of waxing and waning that has been evident in the Old World. Although horses became infected in Suffolk County during 1999, when the virus first was evident in western Long Island, infected dead birds first were evident in 2000 (Figure 4a-e). About as many such birds were evident in 2001 as in 2000, with progressively fewer birds in subsequent years. Indeed, the outbreak virtually disappeared in the eastern US as it swept toward westward. Only one human case was evident in all of New England during 2004, for example, while thousands of people became infected in California and Arizona. The records of avian cases might suggest that risk of infection in Suffolk County is greatest near its western border (Figure 4f). Although few WNV-infected dead birds have been discovered toward the eastern tip of Long Island, this may reflect an artifact because dead birds may simply not be noticed where few people reside, and many more people live toward the west than the east. This pattern in the intensity of transmission, on the other hand, may be real. Because the enzootic vector and reservoir particularly exploit man-made environments, the force of WNV transmission may be greatest in densely inhabited locations.

WNV transmission first becomes evident in Suffolk County during June (Figure 5). Transmission builds thereafter, reaching a maximum during August. Although this pattern generally remained constant between 2000 until 2004, the intensity of transmission steadily waned.

The incidence of human infection in Suffolk County rose incrementally between 2001 and 2003, and declined thereafter (Figure 6). Somewhat anomalous, however, is the absence of human cases during 2000, when WNV-infected dead birds were most evident. The prevalence of infection in mosquitoes, on the other hand, correlated with evidence of avian infection. This

absence of human infection during 2000 may have been due, in part, to personal protection measures that were followed more assiduously during this first year of the outbreak and that were followed less carefully during subsequent years.

The density and distribution of vector mosquitoes were monitored at strategic sites in Suffolk County throughout the course of this outbreak. CDC light traps were distributed most intensively in residential sites throughout the region (Figure 7a). They were most productive of *Culex* spp. mosquitoes. New Jersey light traps were maintained in fixed locations, mainly near salt marsh situations (Figure 7b), and were characteristically most productive of *Aedes sollicitans* mosquitoes. CDC gravid traps were distributed more or less regularly throughout the county (Figure 7c). Because these devices are designed particularly to capture certain kinds of *Culex* mosquitoes in the course of depositing their eggs, such a sample tends to contain older mosquitoes than do light traps. As a result, gravid trap collections are more likely to contain infected mosquitoes than are collections based on light traps. A systematic system for sampling diverse kinds of vector mosquitoes is in place.

Insecticidal aerosols as well as larvicides were applied systematically throughout the period 2000 through 2004 with particular attention to sites that were monitored by the New Jersey light traps (Figure 8a-e). Insecticidal coverage in 2000 was at least twice as great during 2000 than during subsequent years (Figure 8f). The dearth of human infections observed that year (Figure 6) may reflect this more thorough level of insecticidal coverage.

The effect of insecticidal aerosols, applied from the air, was monitored by means of the system of traps described above. Four different applications were analyzed, each in a different location. The Bergen community, sprayed during 2000, was compared to that observed a year later (Figure 9a). This spray application occurred during the end of August, well after the WNV outbreak had crested and after the density of *Culex* mosquitoes had weaned. Little effect was noted. The community designated as Horse was sprayed twice that year (Figure 9b), just before the density of *Culex* mosquitoes began their seasonal pattern of increase and at about the time that density had reached its maximum. Mosquito abundance appears to have declined follow the application. The Calhoun community was sprayed at about the first of September during 2002 (Figure 9c), well after the density of *Culex* mosquitoes had modulated. No marked effect of the application was noted. The Blydenburgh community was sprayed during 2003 (Figure 9d), at about the time

that these mosquitoes had become abundant. The application was followed by a sharp reduction in vector density. When insecticidal aerosols are applied from the air in a timely fashion, the density of the mosquitoes that transmit WNV may be curtailed.

2.3. A pathogen that re-emerges periodically

2.3.1. Eastern equine encephalitis virus

EEE first came to public health attention in 1938 when an outbreak of 35 known cases struck immediately south and west of Boston, MA. More than twenty people died (a mortality rate greater than 50 percent), and half of the survivors experienced debilitating neurologic sequellae. Due to the nature of these residual symptoms, the societal burden of such a surviving case is very large, because full-time care is required, and survivors are often very young. A 1995 estimate was $2.8 million for each survivor (Villari et al., 1995). No other arbovirus is so frequently lethal and debilitating. Because of its lethality, area-wide aerial adulticide applications are the prescribed treatment to reduce the risk of a threatening outbreak. Such applications may have reduced the amplitude of subsequent outbreaks (as measured by human cases). The frequency of EEE isolations and cases in Massachusetts, however, has been increasing (Figure 10).

This infection is maintained in North America in a cycle involving the swamp mosquito, *Culiseta melanura* (Komar and Spielman, 1994). The immatures of this mosquito develop almost exclusively in enclosed sites, mainly in the crypts formed by the raised roots of wetland trees as white cedar in Massachusetts, red maple on Long Island, and tupelo gum in Florida. Ecologically, it is interesting to note that 20th Century regrowth of these trees in concert with wetlands protection policies instituted following more general harvesting of trees. Thus, such crypts are now more common, supporting a more robust population of these mosquitoes. *Cs. melanura* hibernates in its third larval stage and survives until spring provided that the crypt remains flooded and that the pooled water does not freeze to the bottom. A steady pattern of precipitation facilitates survival, because larvae become stranded and die when the water level fluctuates excessively.

EEE perpetuates in an avian cycle involving birds that roost communally in the vicinity of wetlands along the Atlantic coast of the Americas (Hodgson et al., 2001). Starlings appear to comprise the main reservoir in which the virus proliferates. Their capacity to perpetuate this

virus is supported by the size of their communal roosts, their fidelity to a particular roost site, their tendency to disturb feeding mosquitoes before they become replete, and the ability of the virus to proliferate in their bodies and to remain in circulation for extended periods of time sufficient to infect additional mosquitoes. Thus, mosquitoes are more likely to encounter infected birds and then to bite more potentially uninfected birds, so amplifying the infection. Migratory shore birds such as snowy egrets appear to introduce the virus into new sites. This bird was virtually eradicated by Victorian milliners, but became abundant during the late 20th century.

Swamp mosquitoes threaten human health most even though they feed mainly upon birds. Relatively few bites are wasted on mammals, hosts in which the virus proliferates only poorly. These mosquitoes are also extraordinarily long lived. Prevalence of infection may approach one percent. Human infection is generally attributed to the bites of other more general-feeding mosquitoes. *Coquillettidia perturbans*, whose larvae are associated with cat-tail plants, are thought responsible for the occasional cases that occur during mid-summer, while *Aedes vexans*, a late-season, puddle-developing mosquito, is often abundant and found infected coincident with the outbreaks that typically occur in September. These mosquitoes are considered to be "bridge vectors" because they convey infection from the normal maintenance cycle. EEE has been detected elsewhere in the salt marsh mosquito *Aedes (=Ochlerotatus) sollicitans*. Because of its abundance in Suffolk County, and penchant for feeding upon people, it is considered a potential bridge vector of EEE.

The Hockamok Swamp, located in southeastern Massachusetts, is a likely venue of amplification of any EEE cycle that would threaten the residents of Suffolk County. Transmission there has characteristically been more intense than in any other site in the region. Transmission is similarly intense and fairly regular near the Cicero swamp (close to Syracuse, New York), but this more distant site does not likely contribute to risk in Suffolk County. The EEE variant that persisted in the Hockamock during 1990 became extinct after 1993 (Figure 11; Mores et al., in press). A four-year hiatus ensued, but it was replaced transiently by another variant in 1997. A third variant appeared during 1998 and 1999, only to be replaced by a fourth variant in 2000. Florida appeared to be the source of these re-introductions. Virus isolates from New Jersey were similarly inconsistent, but in a differing pattern. Those from Florida, however, were remarkably

constant. These observations indicate that EEE is poorly adapted to the environment in the northern part of the US and that this pathogen is reintroduced periodically from the southern part of the country. Other unpublished observations on Massachusetts isolates preserved since 1970 suggest that massive outbreaks occur solely during the first year of an introduction. An equine outbreak in Mexico in 1996 appears to have been due to a variant introduced from Texas (Brault et al., 1999).

Although no EEE infections in human residents of Suffolk County have yet been recognized, the virus has been detected there in vector mosquitoes and in horses. Risk may increase due to the continued growth of white cedar swamps in nearby Massachusetts and red maple swamps on Long Island. Commercial veterinary vaccines are available for protecting horses. Although horses generally succumb to EEE infection, they are poor reservoirs hosts for this virus. Whereas vaccinating horses may offer certain economic benefits to owners, the immune horses would not reduce risk to people. No commercial EEE vaccine is available for use in people.

2.4. Pathogens that are introduced repeatedly

Malaria was introduced into the Americas during the early days of European settlement and persisted as an important threat to the public health until shortly after World War II. Post-war importation into the US is frequent. One hospital in New York City, for example, received 110 cases between 1968 and 1990 and another 59 between 1991 and 1999 (Kambili et al., 2004). More than a thousand such infections are reported in the country, as a whole, each year (Barat et al., 1997). The trend seems to be increasing, and a few cases generally are acquired within the US each year. More than 60 such localized outbreaks have been reported since 1970, including two children who acquired infection in a summer camp in Suffolk County in 1999. A third case that was diagnosed in 2000 appears to have been associated with this earlier outbreak (Anonymous, 2000). Interestingly, malaria was diagnosed almost simultaneously in three neighbors who lived in Queens, NY, near LaGuardia Airport. Although the mode of transmission remains ill defined, "airport malaria" seems likely. This would involve the transport of infected vector mosquitoes from some distant endemic site and their release once the plane's doors were opened. Alternatively, local anophelines may have acquired infection from a parasitemic traveler. Certain malaria cases in non-travelers may be ascribed to direct transmission of parasites via shared intravenous needles.

2.5. Endemic pathogens that sporadically cause human disease

At least three mosquito-borne arboviral pathogens that cause human disease are endemic to the region. A veterinary arbovirus, blue-tongue virus, is transmitted there by biting midges.

2.5.1. Jamestown Canyon virus

Human disease associated with Jamestown Canyon virus infection represents a rapidly emerging arboviral zoonosis, a public health threat that may be underestimated. Following the original isolation of this arbovirus in 1961, few episodes of human disease were diagnosed, and little attention was paid to the frequent demonstration of seroconversion (indicating previous infection) in people. Clinical disease began to be recognized during the 1980s (Grimstad et al., 1986), particularly in the north central US and in adjacent parts of Canada. Encephalitis is a prominent feature of this disease, and adults are affected as well as children. Transmission in the northeastern states, however, appears to be more intense than the frequency of reported cases would suggest (Grimstad et al., 1987). Various *Ochlerotatus (=Aedes)* mosquitoes (Grimstad et al., 1987) as well as anophelines (DeFoliart, 1986) have been identified as vectors. The spring-hatch mosquitoes, *Oc. (Ae.) abserratus*, *Oc. canadensis*, and *Oc. cinereus*, appear to be the most important vectors of this infection (Andreadis et al., 1994). White-tailed deer serve as reservoirs (Watts et al., 1982), with about half of the Michigan herd acquiring infection each year (Boromisa and Grimstad, 1987). The sera of virtually all such deer react with antigen from Jamestown Canyon as well as Cache Valley virus in Michigan (Neitzel and Grimstad, 1991), while about a quarter of the general deer population in Connecticut are reactive (Zamparo et al., 1997). Risk of human infection corresponds to the spatial and temporal distribution of these animals. The transmission season spans May through July (Grimstad et al., 1987).

2.5.2. La Crosse virus

La Crosse virus is endemic throughout much of the northeastern United States (Gerhart et al., 2001). Some 70 cases of encephalitis due to this infection are reported to CDC each year, mostly in children younger than 16. Symptoms include fever, headache, stiff neck, lethargy, nausea, disorientation, mental confusion, and sometimes seizures. Infection in adults tends to be asymptomatic. Although transmission has, in the past, focused mainly in the Upper Midwest (hence the name), the range of this infection has recently extended toward the south, involving the Carolinas and Tennessee. West Virginia reported more than half the total number of cases

during the late 1990s. This change in distribution has been attributed to the recent invasion of the Asian tiger mosquito, *Aedes albopictus*. This mosquito was imported in used automobile tires from Japan into the vicinity of Houston, Texas, in 1984. It has even invaded Italy, where it is plaguing the citizens of Rome (Anonymous, 2003). This mosquito feeds avidly on people and such small rodents as chipmunks and squirrels and is exceedingly competent as a vector for La Crosse virus (Kitron et al., 1998). Previously, the virus had perpetuated vertically in the tree hole mosquito, *Ae. triseriatus*, mainly by means of inherited infection. Infected mosquitoes may pass the virus to some half of their offspring. During the summer months, the cycle is amplified horizontally through chipmunks. Asian tiger mosquitoes, too, can pass infection by this virus vertically, from adult to egg. Their range has been extending slowing into the northeast, and they seem poised to include Suffolk County. Although tree hole mosquitoes are native to Long Island, the closest La Crosse infections seem to occur in the Albany region. Another somewhat similar Asian import, *Oc. japonicus* has recently invaded New York (including Suffolk County) and New England (Sardelis et al., 2002; Erwin et al., 2002). Its role in La Crosse transmission, however, has not yet been established.

The disease caused by La Crosse virus can be exceedingly burdensome. Although infection generally is silent, some children suffer lasting neurologic sequellae (Utz et al., 2003). Each case costs society at least $48,000 and some more than $3,000,000. Half of affected children experience seizures and more than one in 10 suffer from gravely increased intracranial pressure (McJunkin et al., 2001; Balkhy and Schreiber, 2000). Loss of cognitive and behavioral function may continue for more than a year.

Severe cases tend to cluster locally, perhaps in the vicinity of a breeding site in which a particularly virulent variant of the virus is being passed vertically (Kitron et al., 1997). Tree hole mosquitoes as well as Asian tiger mosquitoes deposit their eggs in the basal holes of hardwood trees, as well as in such artificial containers as discarded automobile tires. Infestations of these mosquitoes in a residential site may consistently plague families nearby.

2.6. Exotic pathogens that may yet be introduced

2.6.1. Sindbis virus

An outbreak of a novel disease became evident in Finland in 1981 when a single physician saw some 73 patients experiencing the novel syndrome caused by this pathogen (Turunen et al., 1998). This febrile disease is characterized by a diffuse rash and arthritis, with some patients becoming severely immobilized. The name, Pogosta disease was applied to this syndrome, and Sindbis virus proved to be the etiologic agent (Kurkela et al., 2004). Discrete outbreaks were recorded in 1981 to 1982, 1988, and in 1995. A startling 11 percent of Finns have been infected by this pathogen (Laine et al. 2003). More than 2,000 cases have already been diagnosed in the country, with 18 cases per thousand residents occurring in Karelia Province (Brummer-Korvenkontio et al., 2002). Sindbis virus appears to be an important cause of rheumatoid arthritis in Scandinavia and Central Europe.

Sindbis virus may have been introduced into Finland from the Middle East. The pathogen first was recognized in Egypt during the 1950s and continues to circulate there (Turell et al., 2002). Various *Culex* mosquitoes serve as vectors, including the house mosquito, *Cx. pipiens*, and house sparrows appear to serve as the reservoir. Migratory birds are the likely vehicles of importation of this pathogen (Malkinson et al., 2001; Sammels, 1999). Sindbis virus seems a likely candidate for introduction into the northeastern US because it shares essential biological features with WNV and because it seems already to have been carried into Europe and Australia.

2.6.2. Rift Valley fever virus

Rift valley fever virus is a desert-adapted African pathogen that has been responsible for devastating epidemics following the occasional heavy rains or dam construction that result in local flooding. The vector in these desert situations is *Aedes macintoshi*, a mosquito whose eggs can withstand decades of drying and whose reproductive tissues remain stably infected by this virus from generation to generation. Transmission in these desert situations, then, is entirely vertical. Amplification by transmission through some avian or mammal host may be uncommon and would seem to be unnecessary. A severe illness, however, follows the bite of one of these infected mosquitoes, affecting people as well as cattle, goats and sheep (Gerdes, 2002). The human disease includes an influenza-like illness, frequently accompanied by encephalitis or retinitis. In hoofed animals, abortion is frequent, as is hepatitis, particularly in the young.

Several outbreaks of Rift Valley fever have struck the Nile Valley of Egypt, first in 1979 and 1980, again in 1993, and once again in 2001 and 2002 (Madani et al., 2004). *Ae. macintoshi* is not present in Egypt; instead, the virus cycles through house mosquitoes, *Cx. pipiens*, and a human reservoir. Nearly a thousand cases were recorded in the more recent of the two outbreaks, and these people experienced fever, nausea, vomiting, abdominal pain, diarrhea, jaundice, encephalitis, severe bleeding, vision loss, jaundice, and severe anemia. The mortality rate was 14 percent. These Egyptian outbreaks may have been imported when infected camels were brought in from Sudan (Abd el-Rahim et al., 1999). The potential for Rift Valley virus to invade new territories is illustrated further by a series of outbreaks that have occurred on the Arabian Peninsula in recent years. This pathogen, however, has not as yet crossed the Mediterranean or spread across Gaza into Israel.

2.6.3. Japanese encephalitis virus

Japanese encephalitis virus is another candidate for introduction into the United States, and the Suffolk County environment appears generally suitable. It constitutes an important public health burden throughout much of Asia, affecting China, Southeast Asia, and the Indian subcontinent. This pathogen appeared for the first time on the Australian Continent on the Western Cape York Peninsula in 1998. Subsequent study, however, failed to derive evidence that it has persisted there (Johansen et al., 2003).

2.6.4. Usutu virus

This novel arbovirus, designated as Usutu virus, was recognized recently in Central Europe (Chvala et al., 2004). Before 2001, Usutu was known solely in southern Africa, where it is maintained in a cycle involving certain birds and *Culex* mosquitoes. The virus subsequently became endemic in Central Europe where it poses a severe environmental threat. Rodents appear to be accidental hosts, and the virus was isolated once from a person who was experiencing fever and a rash. No human neurological involvement, however, has yet been attributed to this virus. Massive mortality in birds followed its introduction into Austria. The European blackbird, (*Turdus merula*), an analog of the American robin (*T. migratorius*), is particularly vulnerable to this pathogen, and about a third of the population is said to have been

lost each year. Many other European songbirds have suffered, as well. The vehicle of introduction of Usutu virus into Central Europe has not been identified.

As in Austria, Usutu virus seems a likely candidate for introduction into North America, and the residents of Suffolk County should be alert to the possibility that this threat to bird-life may appear there. The circumstances that would permit transmission exist because *Cx. pipiens* mosquitoes appear to serve as vector and a variety of birds as reservoir.

2.7. Tick-transmitted pathogens

The novel complex of tick-borne pathogens that first became evident in southern New England and Suffolk County during the 1970s illustrates basic principles that apply to emerging mosquito-borne infections and to certain legal responsibilities of communities in the face of such an event. These pathogens include Lyme disease (caused by a syphilis-like spirochete, *Borrelia burgdorferi*), human babesiosis (caused by a malaria-like protozoan, *Babesia microti*), and HGE (caused by a typhus-like rickettsia, *Anaplasma phagocytophilum*). Another microbe, known as deer tick virus (related to the burdensome tick-borne encephalitis of Europe), which is also transmitted in the region, may be pathogenic in people but has not yet been implicated. These pathogens are maintained in cycles involving the white-footed mouse (*Peromyscus leucopus*) and deer ticks (*Ixodes dammini*), the common vector. Although these pathogens have long been endemic in the region (Marshall et al. 1994), they began to affect human health only recently, when the vector tick began to proliferate there. Rodent cycles of *Ba. microti* and *A. phagocytophilum* were well documented during the 1930s on Martha's Vineyard Island in Massachusetts (Tyzzer 1938). No human infections occurred at that time because the presumed vector tick, the mouse tick (*I. muris*), rarely feeds on people. The mouse tick has since become virtually extinct, perhaps due to the recent proliferation of deer ticks. Although the larvae and nymphs of these ticks focus on mice, they do feed on people far more often than do mouse ticks, thereby facilitating their role as bridge as well as maintenance vectors of all of these infections. Interestingly, these profligate vectors of pathogens even transmit a babesial infection of deer (*Ba. odocoilei*). Because the adult stage of these vector ticks feed and mate mainly on white-tailed deer (*Odocoileus virginianus*), transmission depends on the presence of at least eight of these animals per square mile (Awerbuch at el., 1994; Wilson et al., 1984). Deer were virtually extinct in eastern North America during the 1800s, but began to proliferate there during the last

century (Kiszewski and Spielman, 1993). "Although deer formerly were common throughout Long Island, they were [at about 1899] restricted to an area of about 27 square miles in the townships of Brookhaven and Islip" (Severinghaus and Brown, 1956). They began to proliferate before World War II and have become distributed throughout much of Suffolk County and appear to be reaching the eastern part of Nassau County. These animals have continued to increase in abundance, and are frequently encountered in residential communities.

The first known human victim of babesiosis in North America acquired infection on Nantucket Island, Massachusetts, in 1969. After some delay, her condition was diagnosed incorrectly as malaria (due to *Plasmodium falciparum*), and alarmingly, drug resistant malaria. She recovered and helped diagnose infection in the second case of "Nantucket fever," in 1973, in a friend. The frequency of infection has progressed slowly on Nantucket Island, with some 15 to 20 human infections diagnosed each year. This condition became evident on Shelter Island during the late 1970s and in certain other Suffolk County communities during subsequent decades, such that Long Island now ranks with Nantucket as a central focus of infection.

Although the first report of Lyme disease in North America was recorded in Wisconsin in 1969, the outbreak was first recognized in Old Lyme, Connecticut, in 1975 (Steere et al., 1994). As in the case of babesiosis, residents of the region contributed much to the recognition of the condition and to efforts to resolve the problem. Two mothers of affected children noted this peculiar clustering of cases and, independently brought this observation to public attention. Residents associations and nonprofit conservation organizations in affected sites helped carry this process forward. Local physicians and various advocacy organizations have contributed their share to public recognition of these linked outbreaks. The work of the CDC in combating this complex of infections was exemplary.

Industry played a mixed role in combating this outbreak of multiple pathogens. A vaccine that protects against the agent of Lyme disease, "LYMErix," was developed and marketed by SmithKline Beecham (Steere et al., 1998). After several years of successful distribution, this product was withdrawn from the market, presumably because personal injury law suits threatened profitability. One company, EcoHealth, markets a device designed to destroy those ticks that come in contact with treated mice (Mather et al., 1987) and has found a ready market in the Hamptons and on Fire Island. A somewhat similar system, "Max-Force" (or the "mouse

house,") became available during 2004. The "Four Poster" apparatus is a baited acaricide distribution device targeted at deer. Although it initially appeared to be promising, its use has largely been abandoned because the agent of chronic wasting disease may be transmitted between deer feeding at a common point. This pathogen of deer is closely related to the agent of bovine spongiform encephalitis. At least one company, "White Buffalo," provides deer-management services in an apparently sustainable manner. Insecticides and repellents find a ready market where these infections have become established. Interventions designed to protect against outbreaks of vector-borne infection face unusually difficult challenges.

Figure 1. Seasonal distribution of human cases of WNV infection in the northeastern United States. Epidemiological week 36 occurs during mid-September.

Figure 1. Seasonal distribution of human cases of WNV infection in the northeastern United States. Epidemiological week 36 occurs during mid-September.

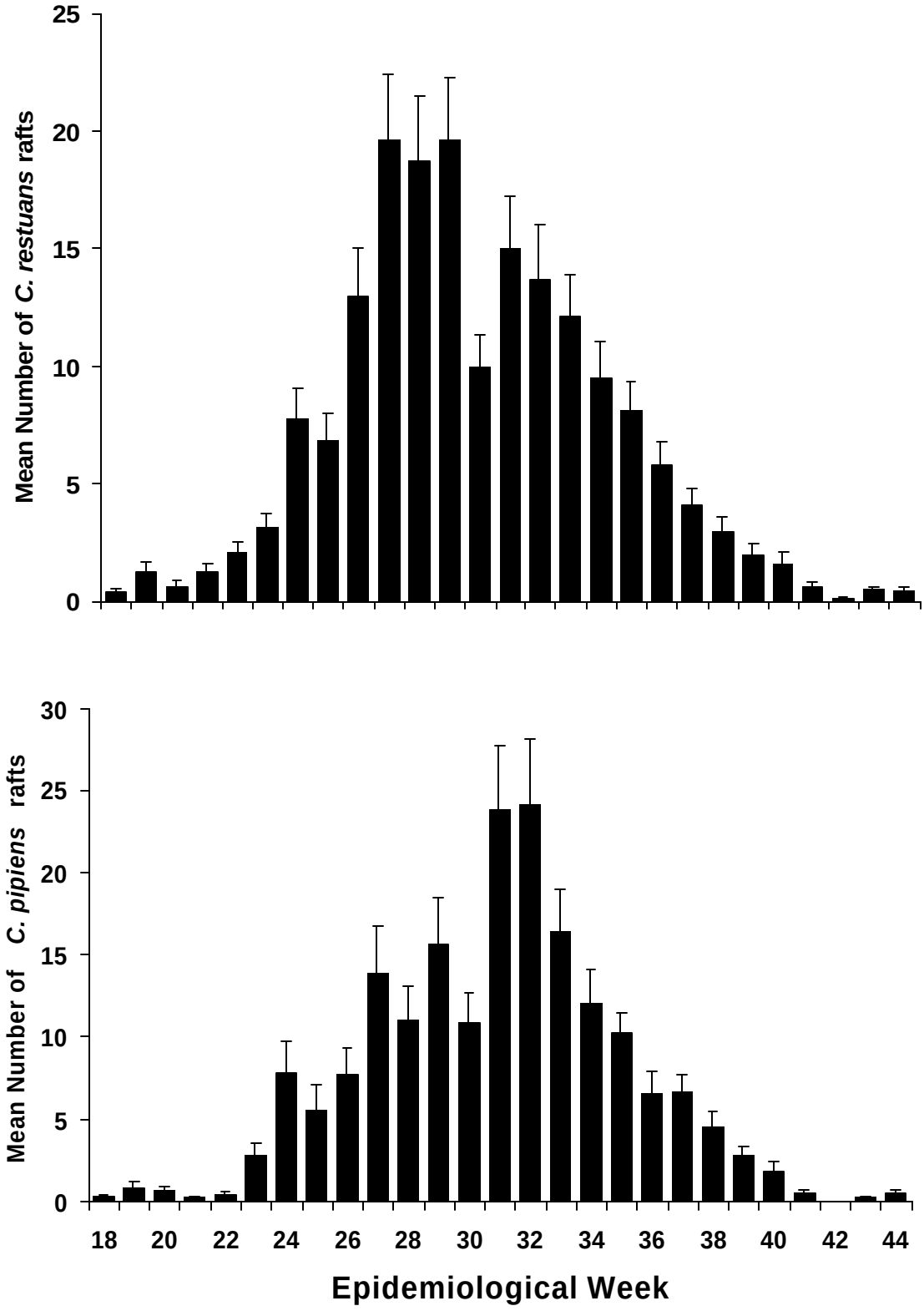


Figure 2. Season of reproductive activity of *Culex pipiens* in the northeastern United States. Epidemiological week 32 occurs during mid-August.

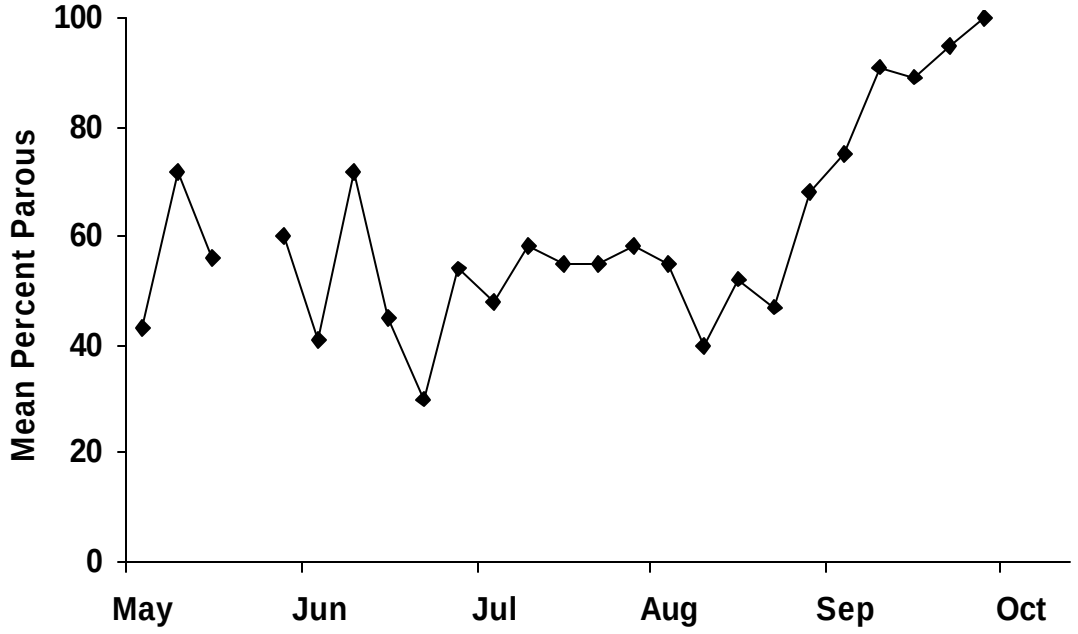


Figure 3. Seasonal changes in longevity of host-seeking *Culex pipiens* mosquitoes in the northeastern United States. Longevity is expressed in terms of parity, the proportion of mosquitoes that had previously laid at least one batch of eggs.

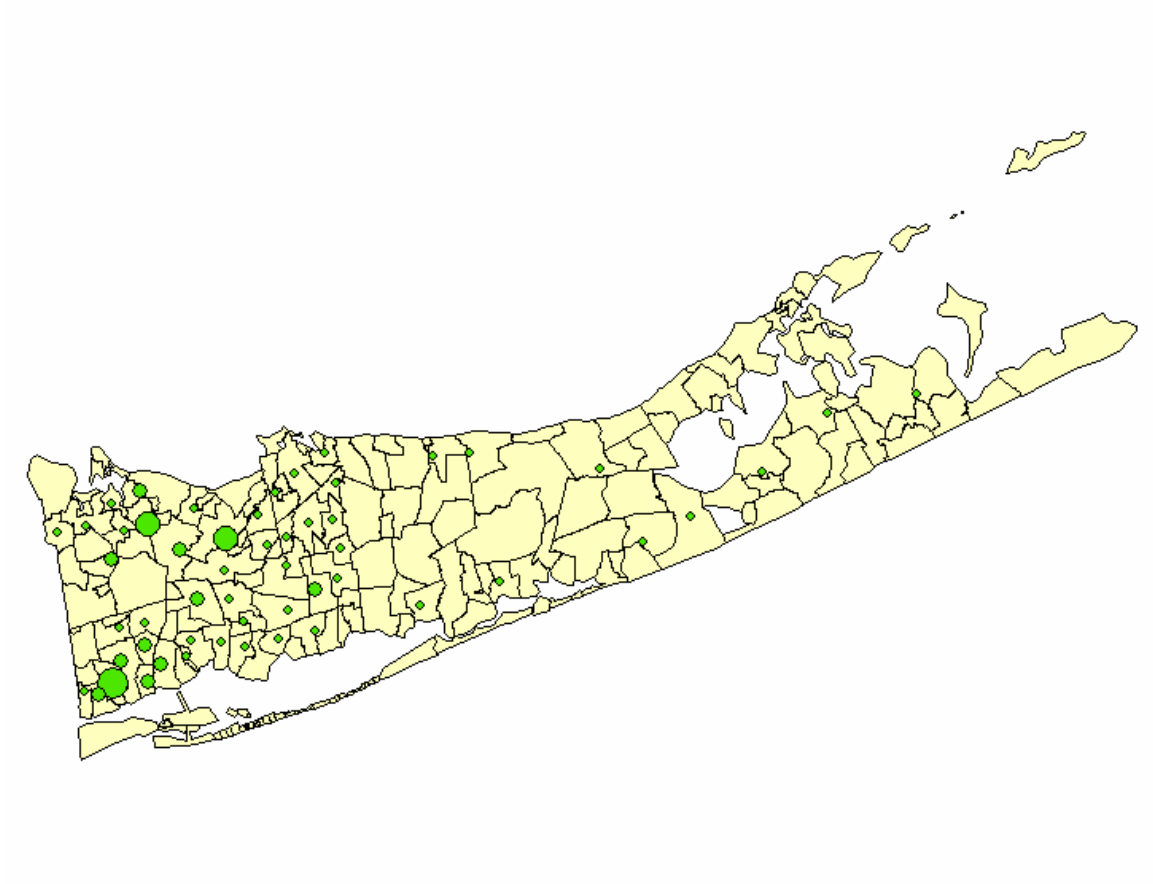


Figure 4a. Spatial distribution of WNV-infected birds discovered in Suffolk County during 2000.

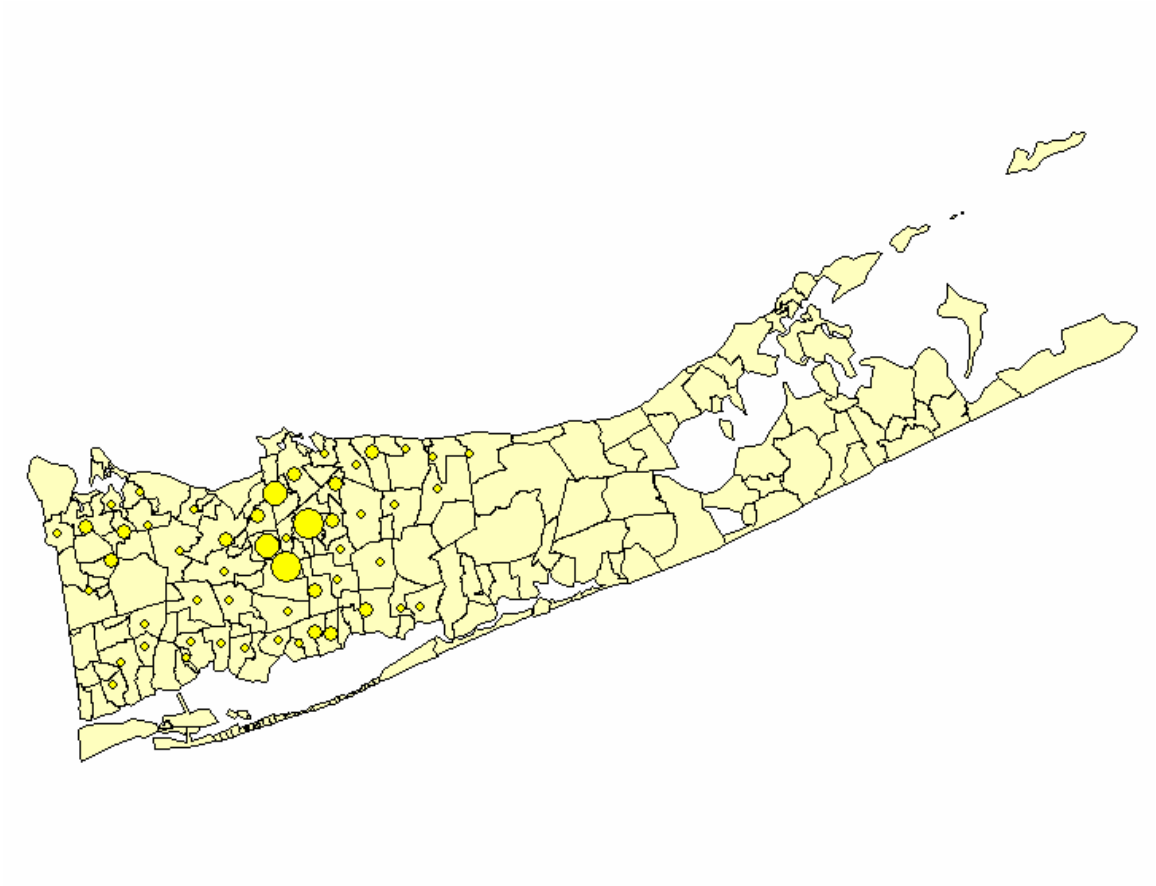


Figure 4b. Spatial distribution of WNV-infected birds discovered in Suffolk County during 2001.

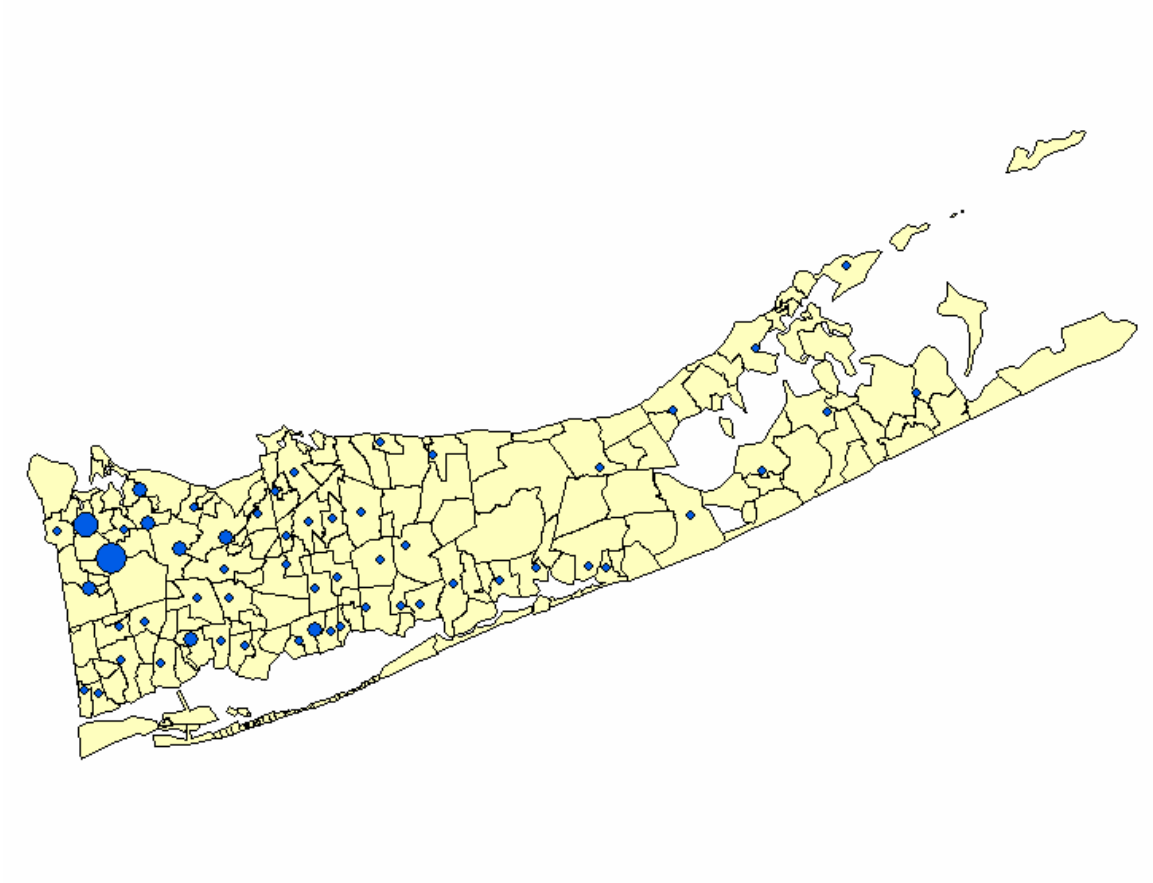


Figure 4c. Spatial distribution of WNV-infected birds discovered in Suffolk County during 2002.

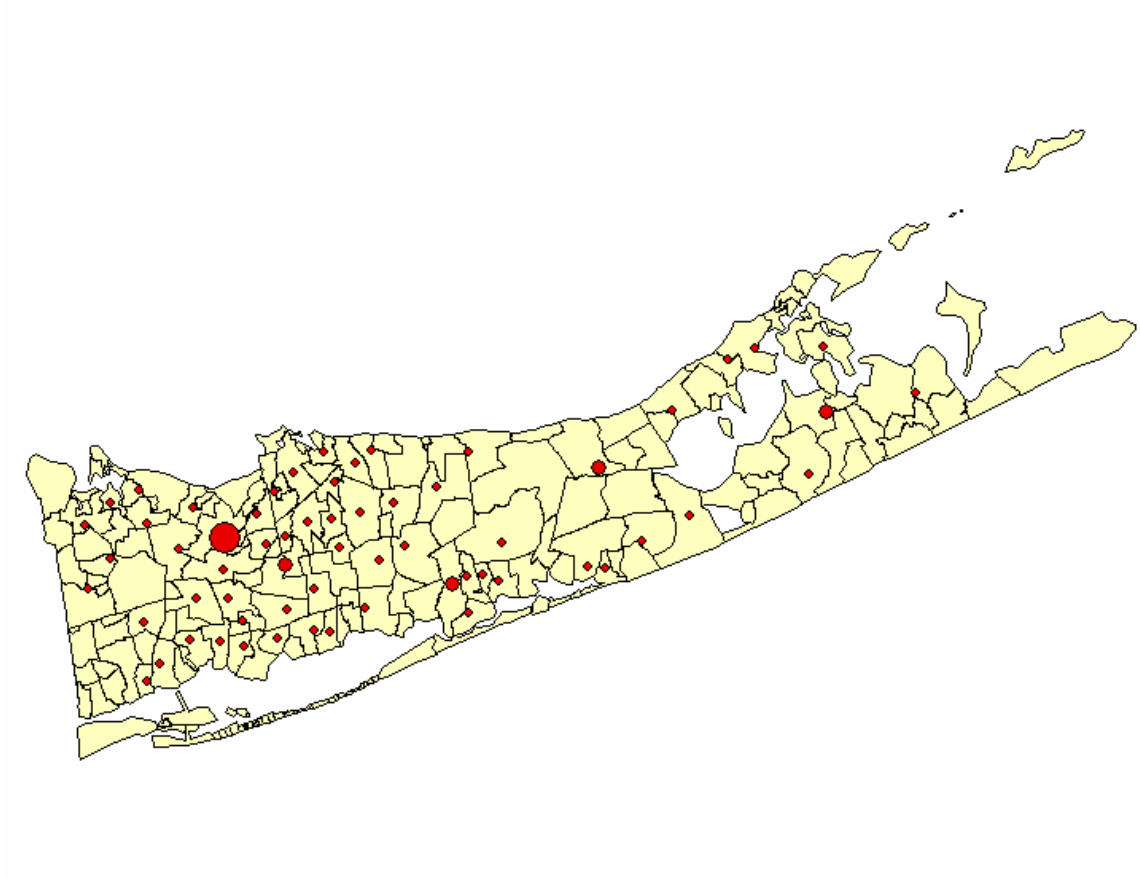


Figure 4d. Spatial distribution of WNV-infected birds discovered in Suffolk County during 2003.

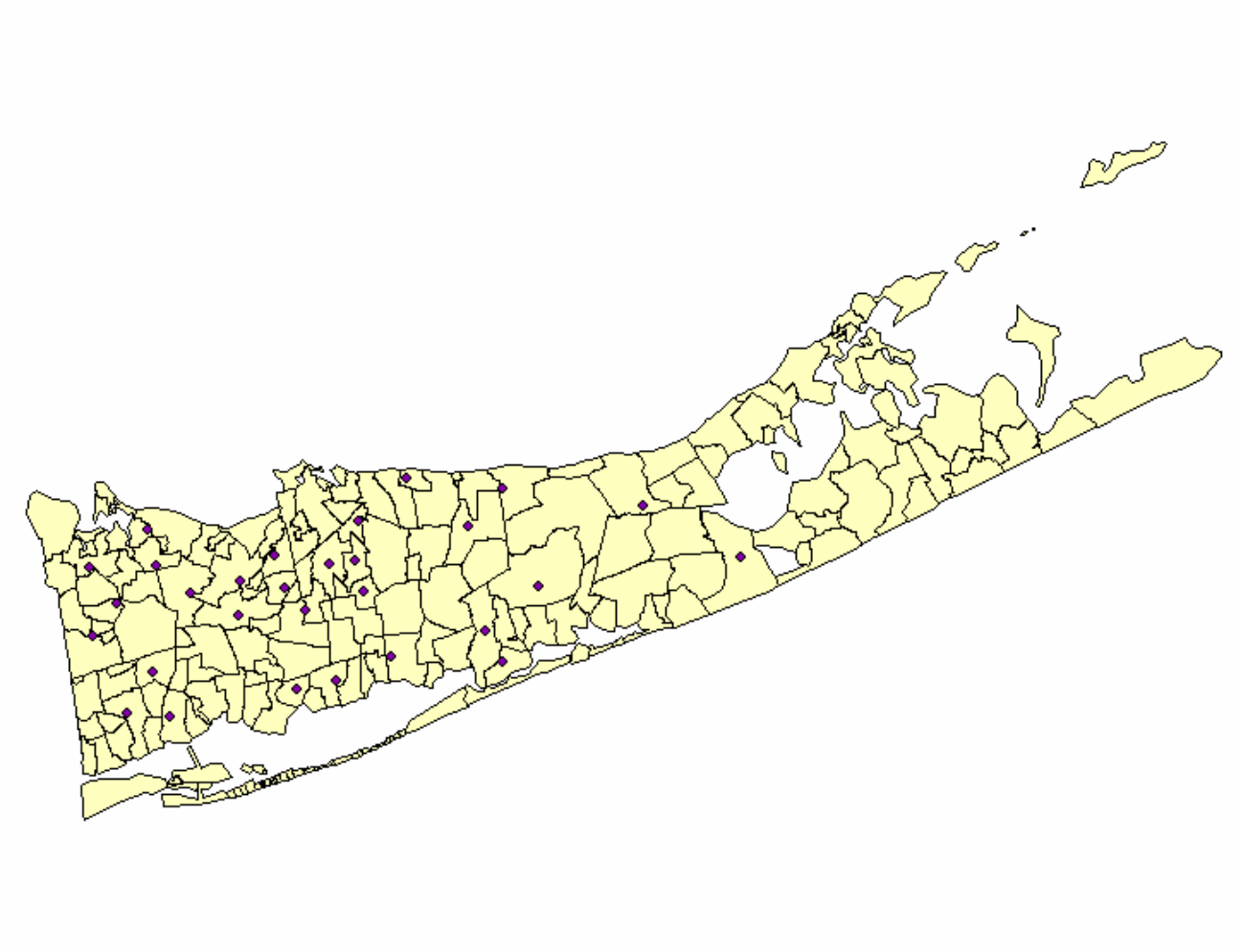


Figure 4e. Spatial distribution of WNV-infected birds discovered in Suffolk County during 2004.

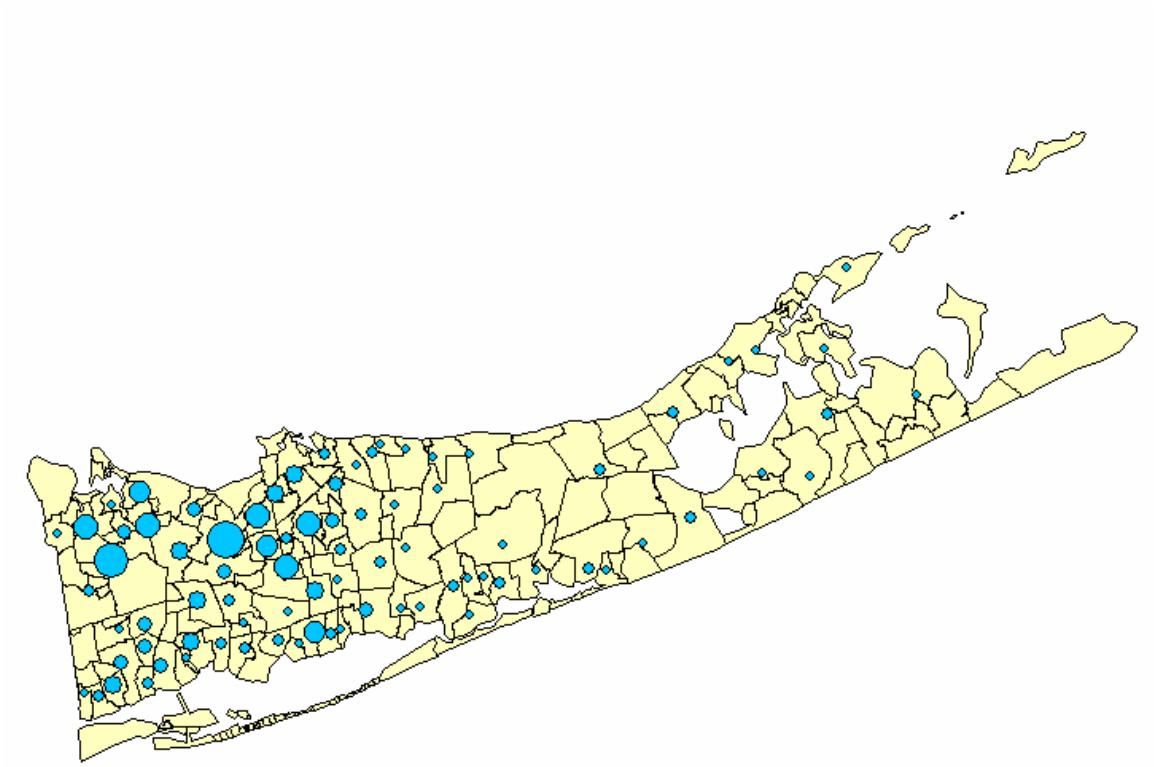


Figure 4f. Spatial distribution of WNV-infected birds discovered in Suffolk County during 2000-2004.

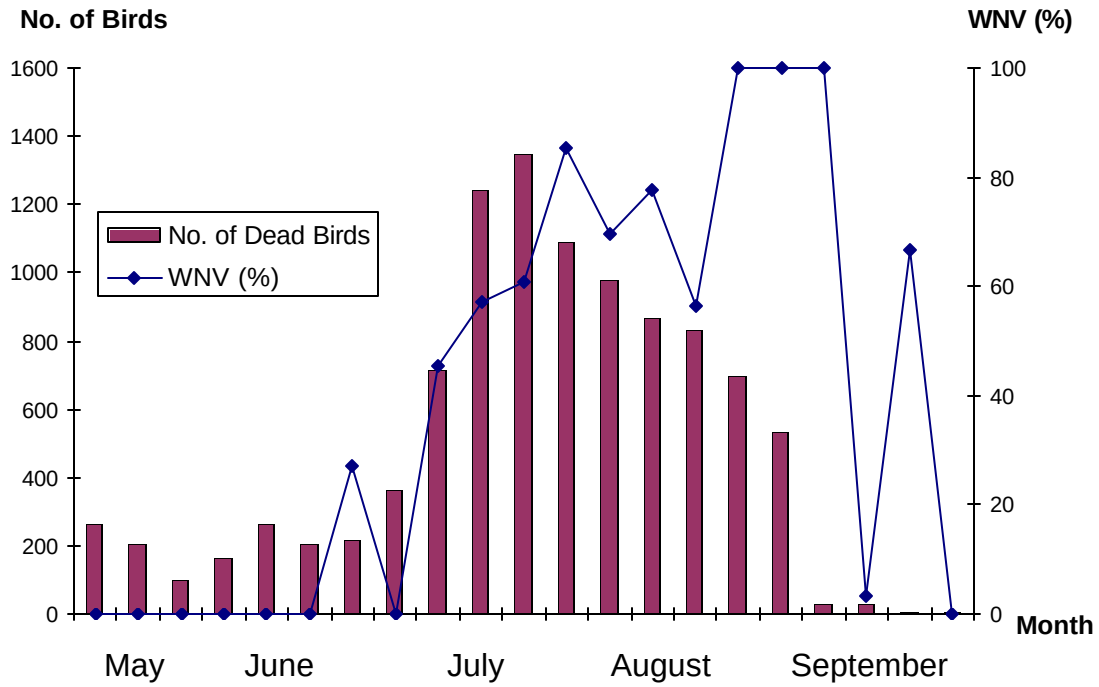


Figure 5a. Temporal distribution of WNV-infected birds discovered in Suffolk County during 2000.

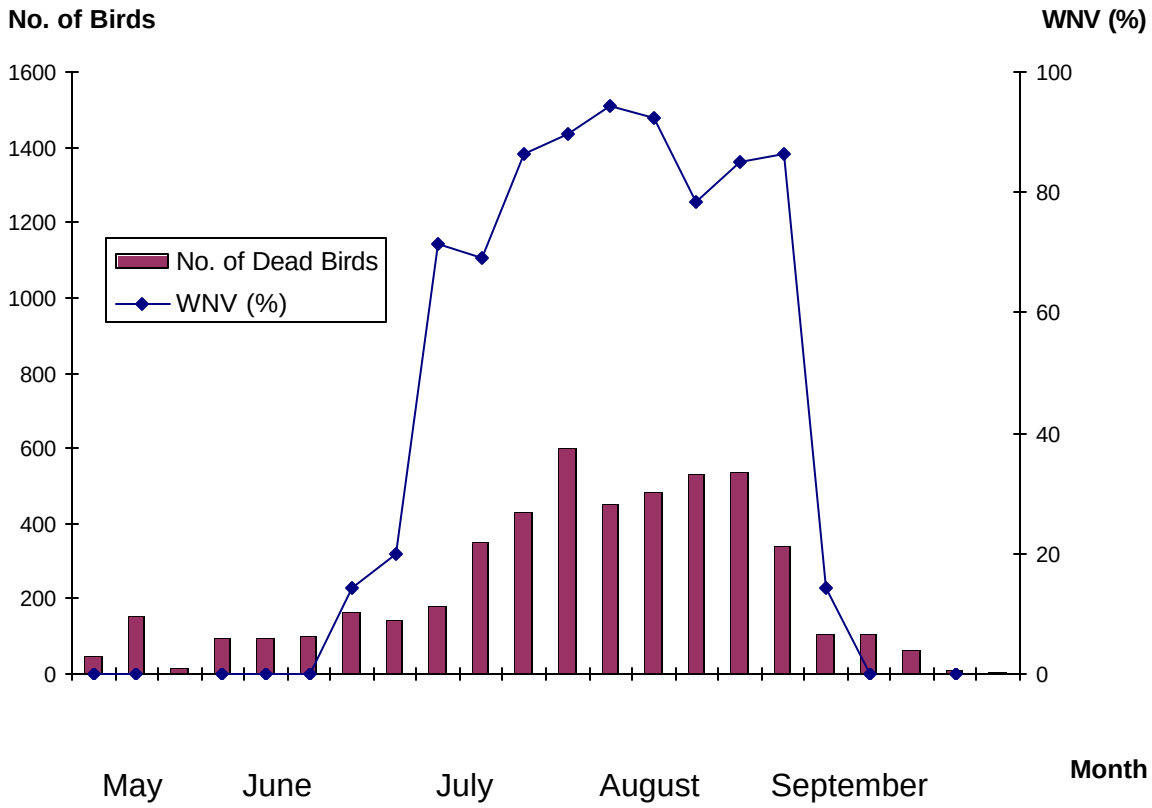


Figure 5b. Temporal distribution of WNV-infected birds discovered in Suffolk County during 2001.

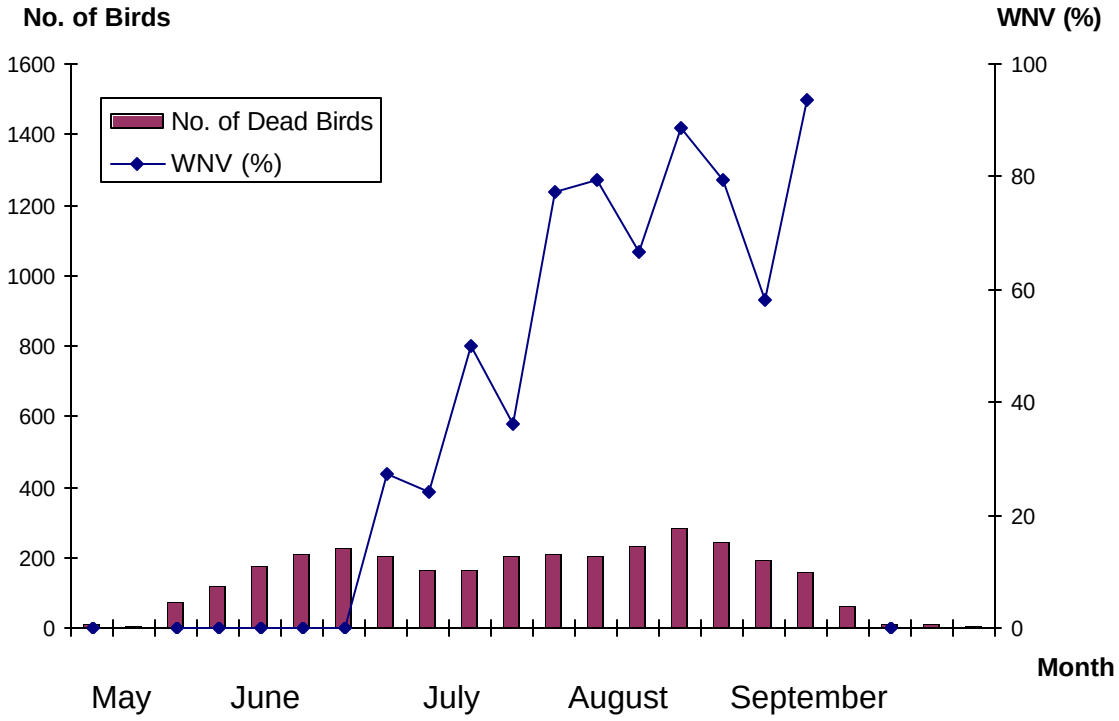


Figure 5c. Temporal distribution of WNV-infected birds discovered in Suffolk County during 2002.

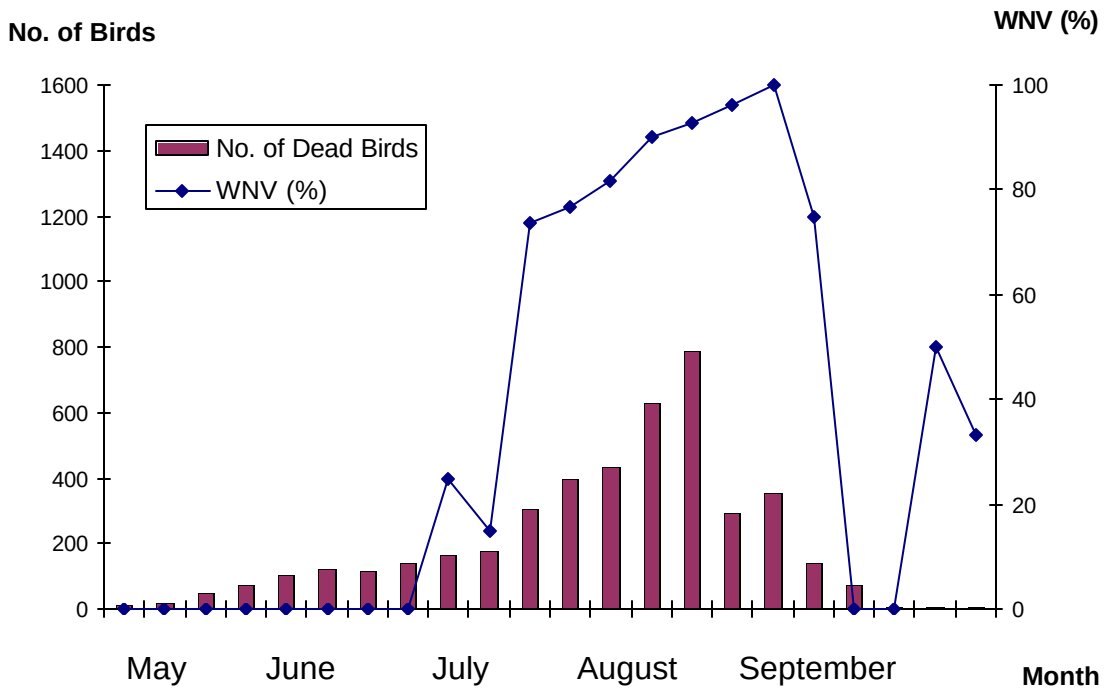


Figure 5d. Temporal distribution of WNV-infected birds discovered in Suffolk County during 2003.

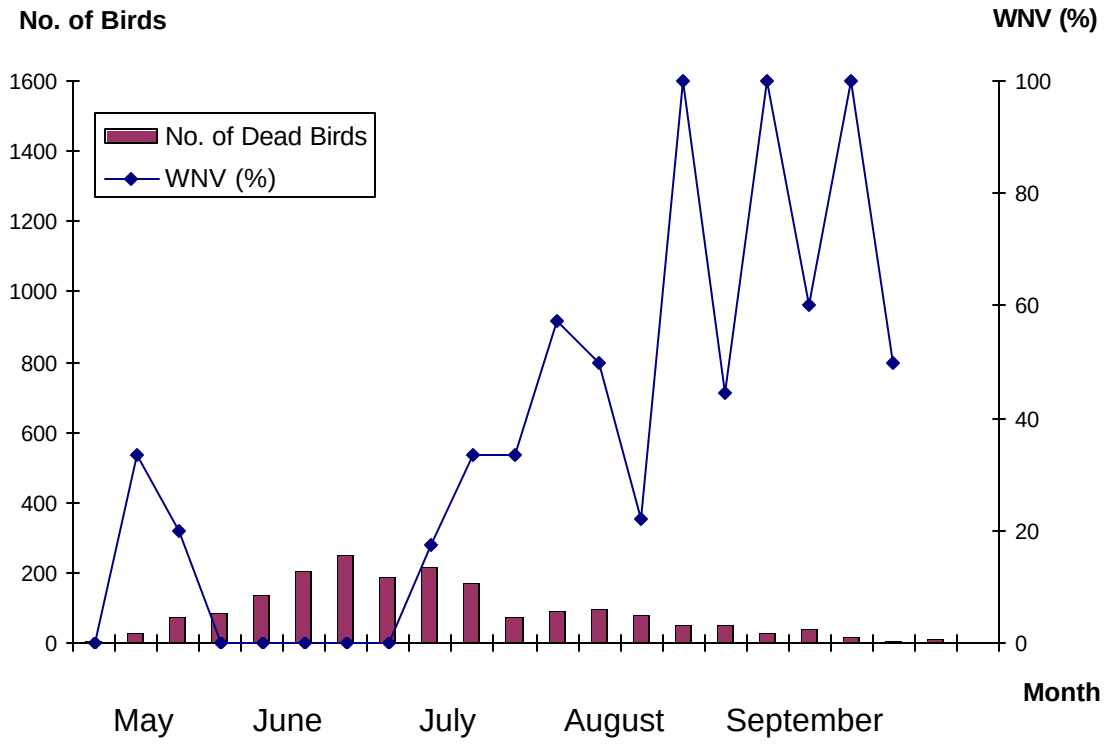


Figure 5e. Temporal distribution of WNV-infected birds discovered in Suffolk County during 2004.

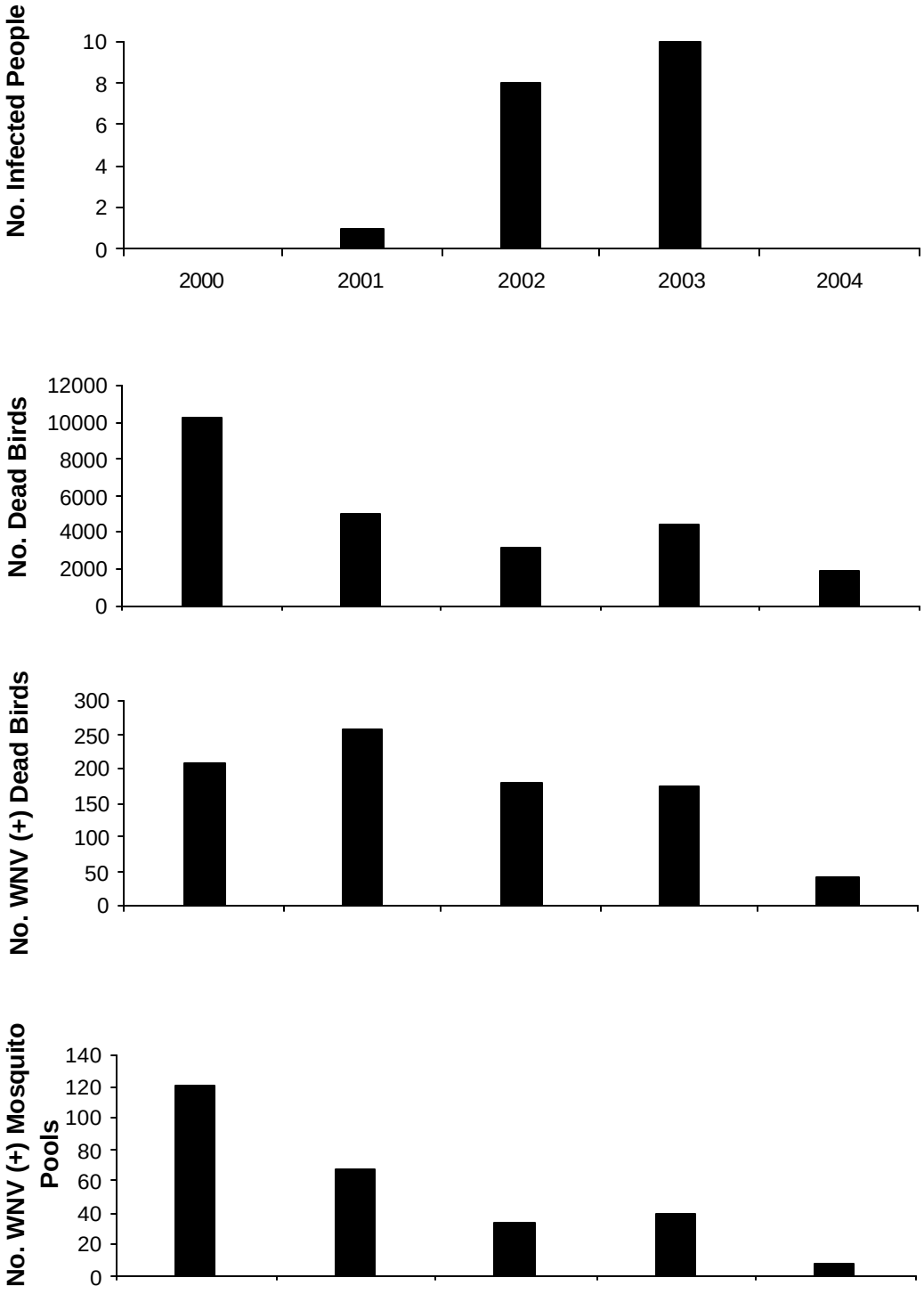


Figure 6. Intensity of WNV transmission in Suffolk County during 2000-2004.

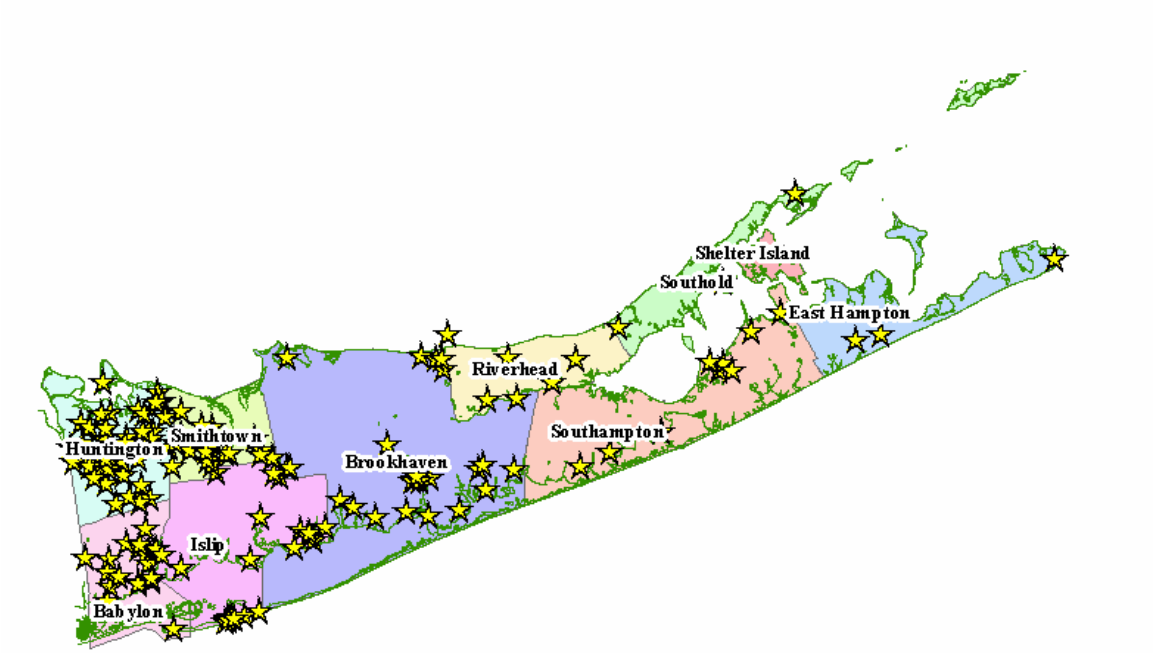


Figure 7a. Distribution of CDC light traps, used for monitoring the density of vector mosquitoes during 2000-2004 in Suffolk County.

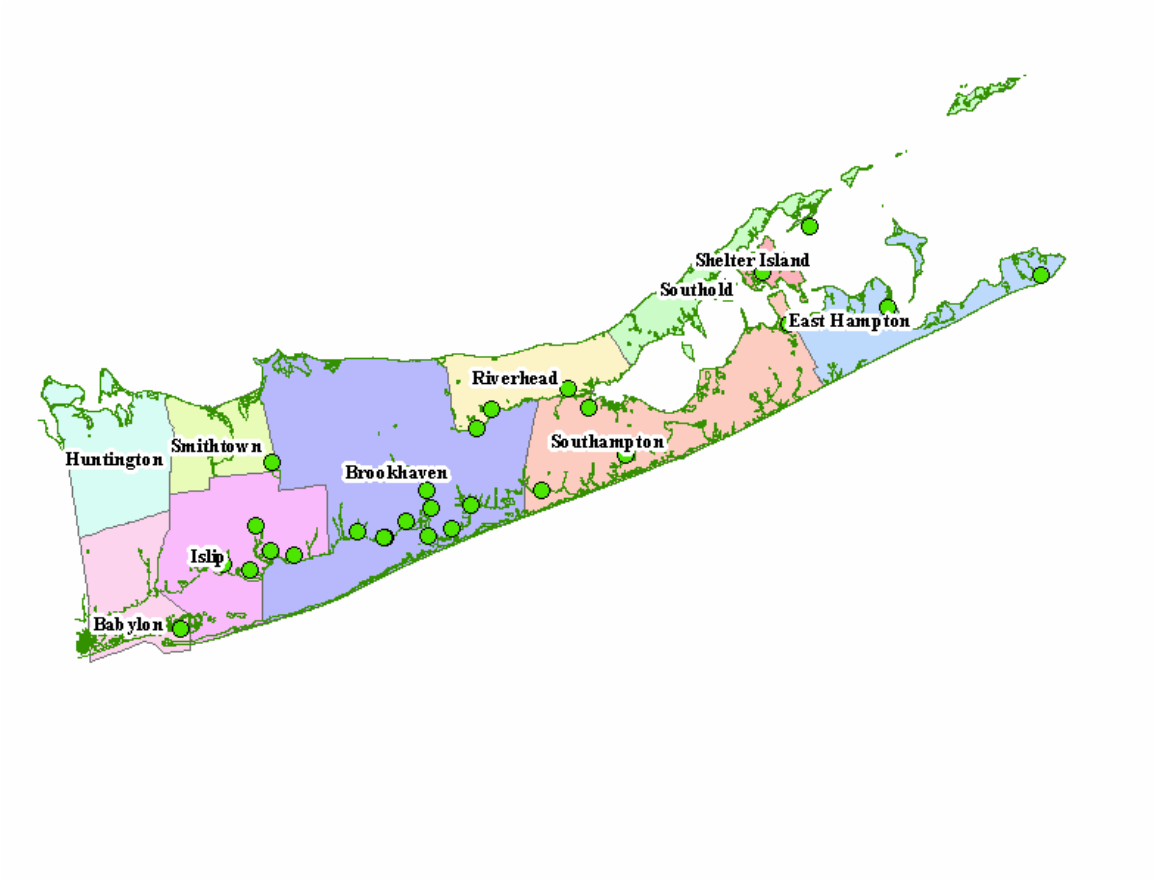


Figure 7b. Distribution of New Jersey traps, used for monitoring the density of vector mosquitoes during 2000-2004 in Suffolk County.

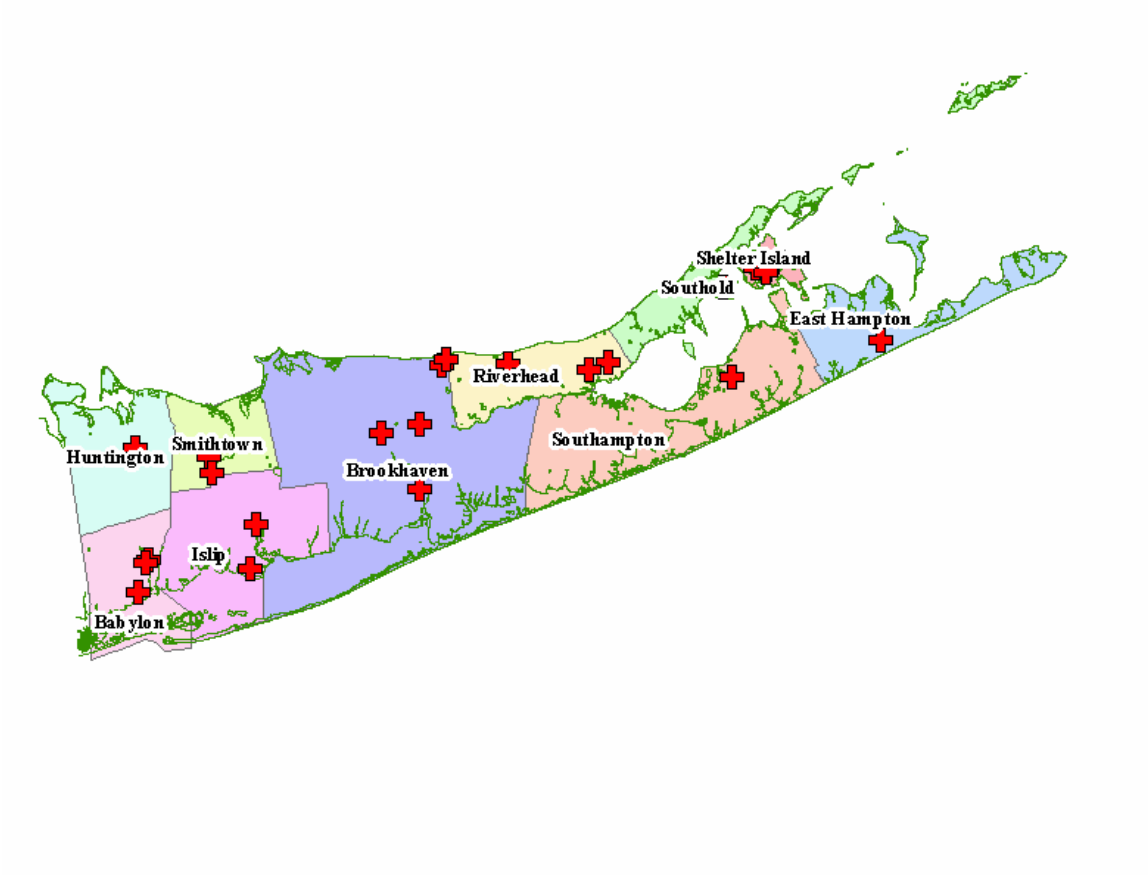


Figure 7c. Distribution of Gravid traps, used for monitoring the density of vector mosquitoes during 2000-2004 in Suffolk County.

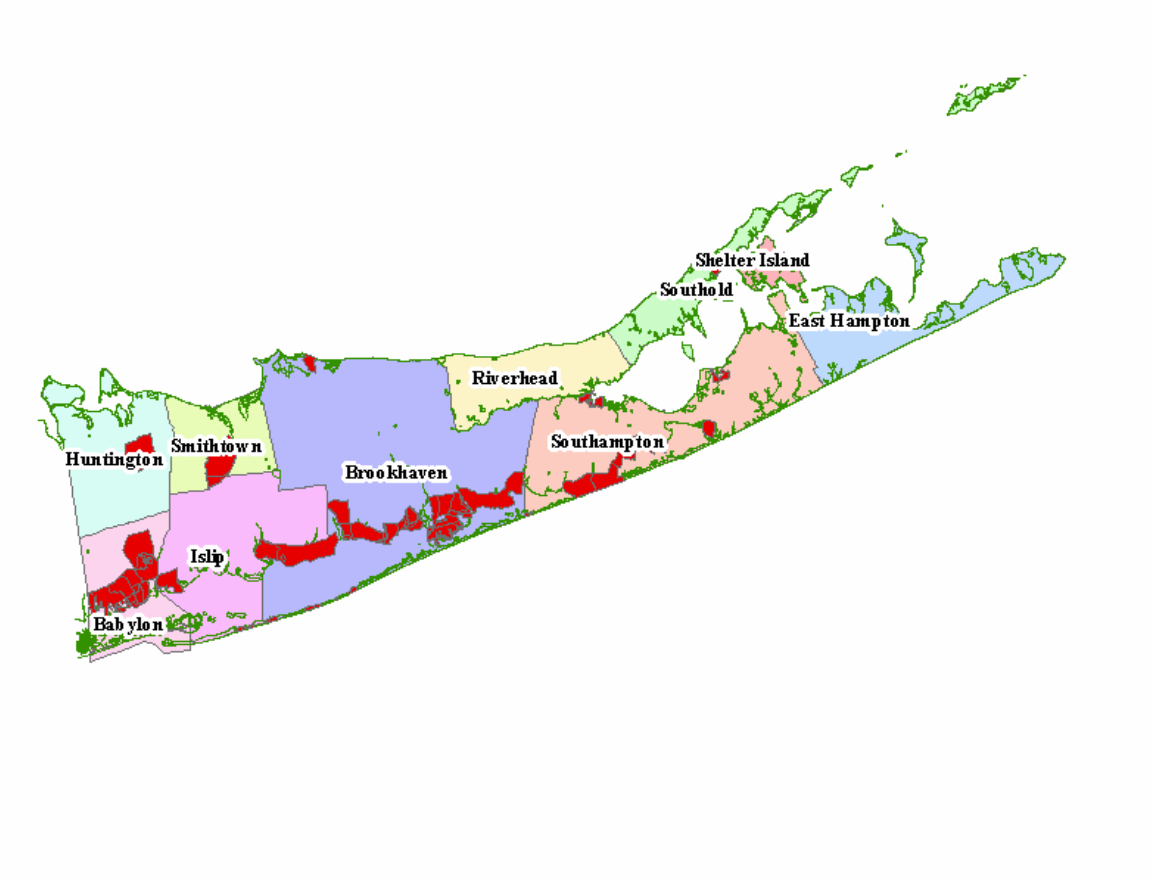


Figure 8a. Distribution of insecticide in Suffolk County in 2000.

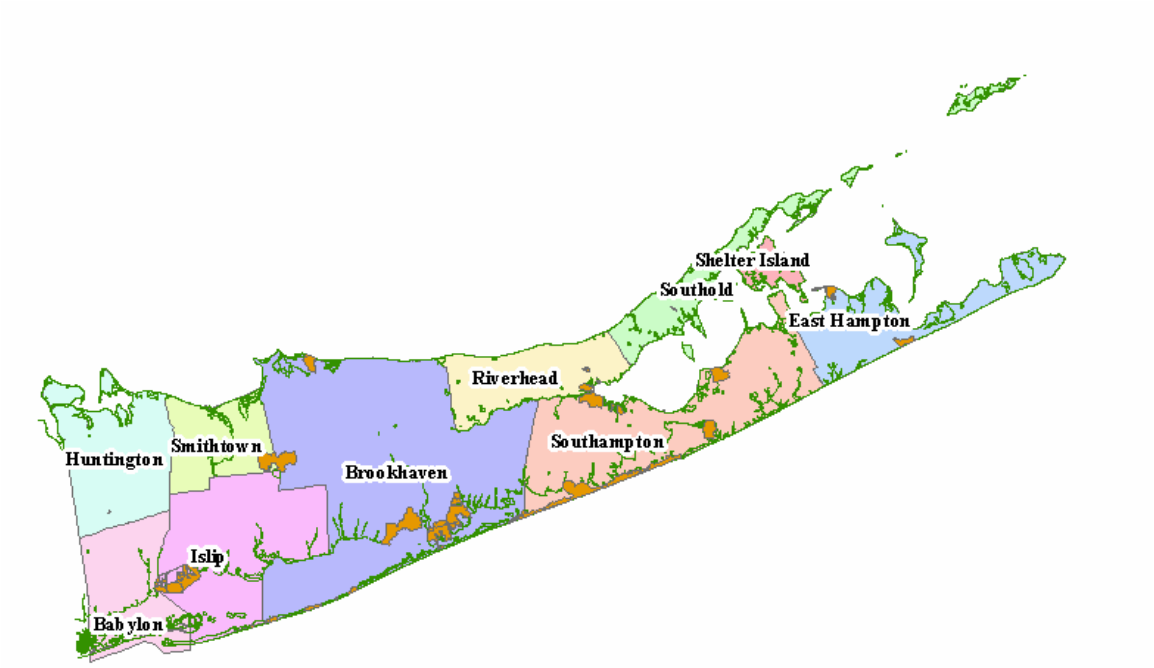


Figure 8b. Distribution of insecticide in Suffolk County in 2001.

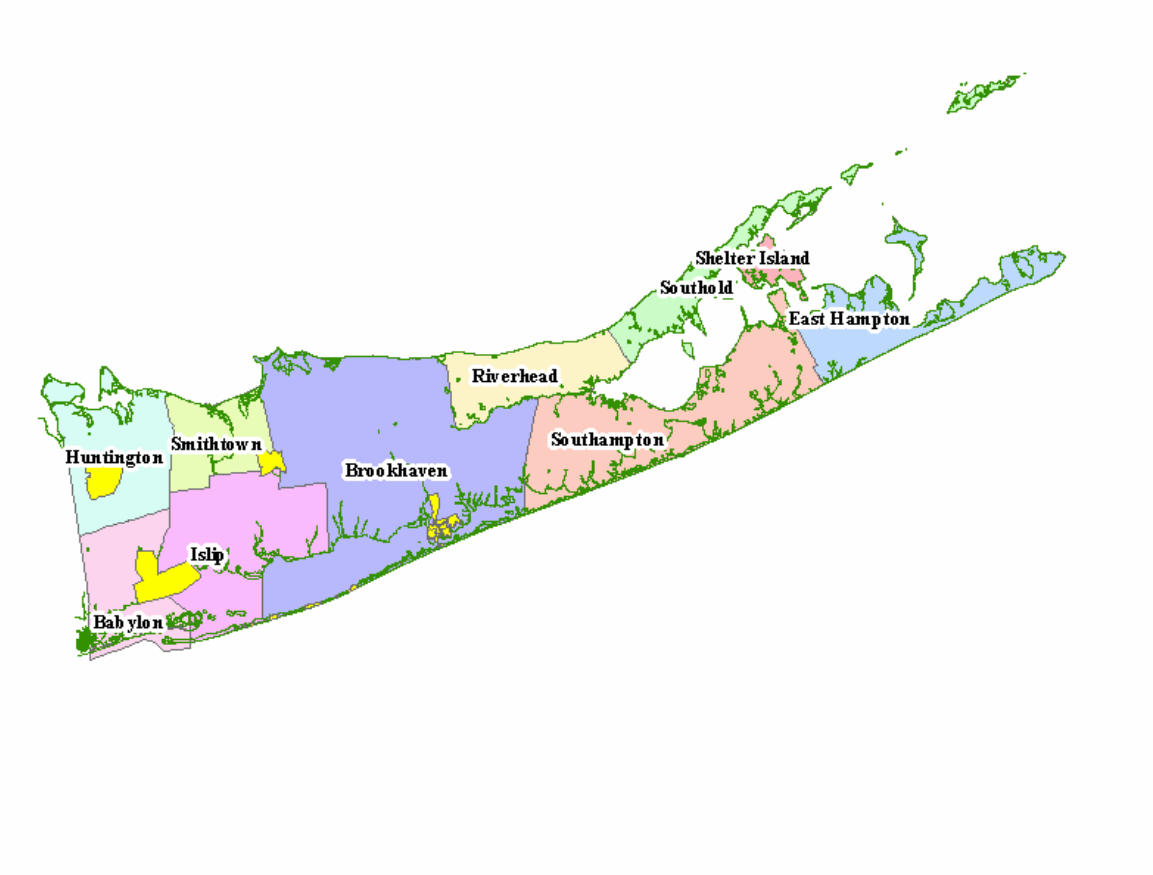


Figure 8c. Distribution of insecticide in Suffolk County in 2002.

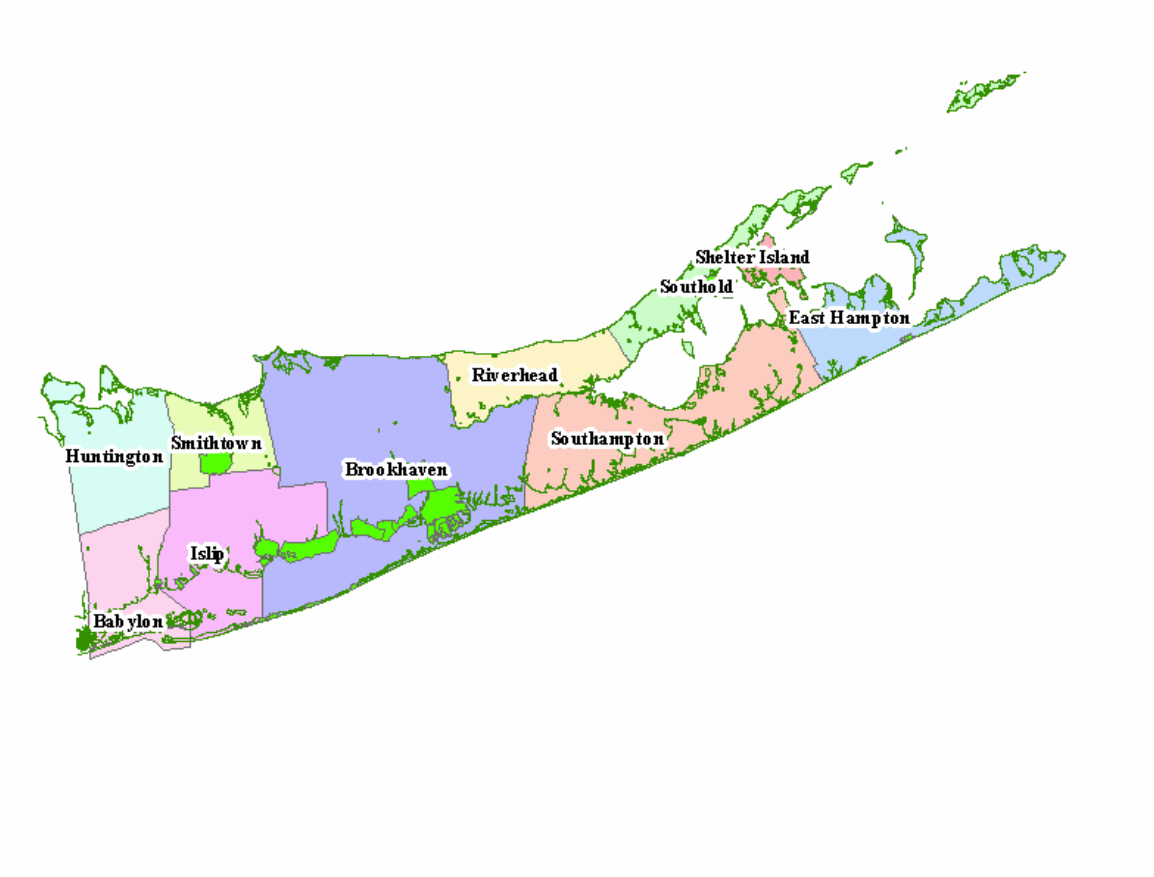


Figure 8d. Distribution of insecticide in Suffolk County in 2003.

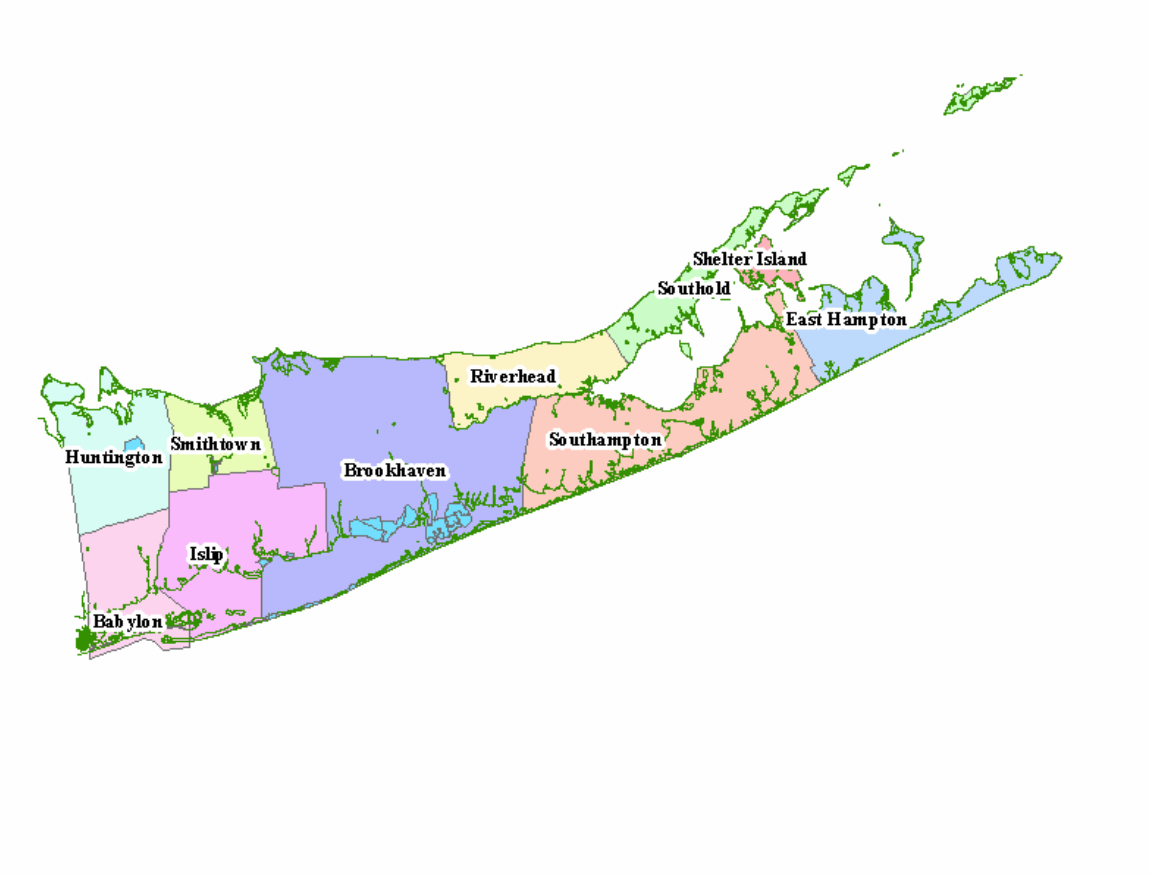


Figure 8e. Distribution of insecticide in Suffolk County in 2004.

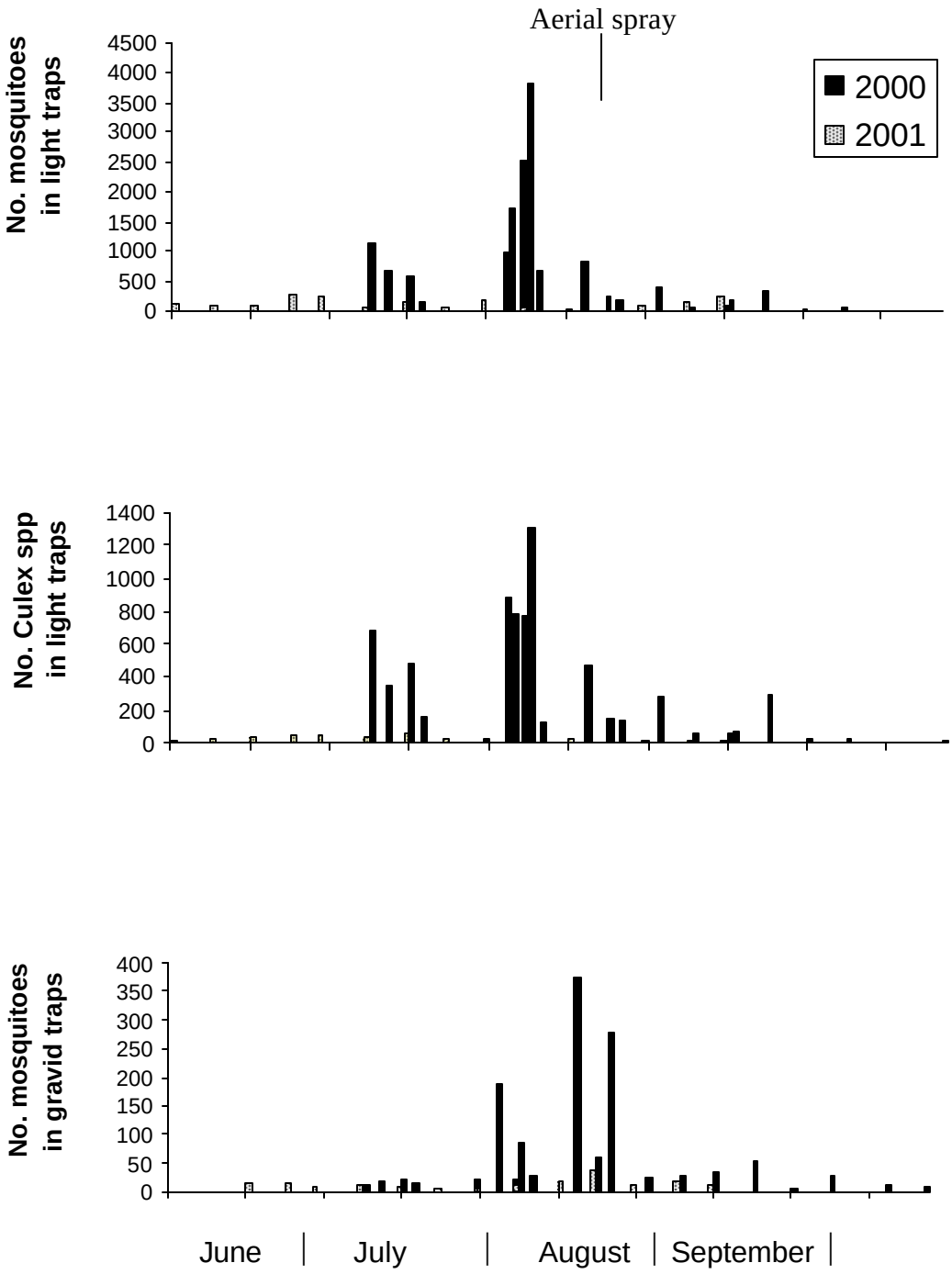


Figure 9a. Effect of insecticide aerosols, applied in 2000, on the density of mosquitoes in the Bergen community in Suffolk County.

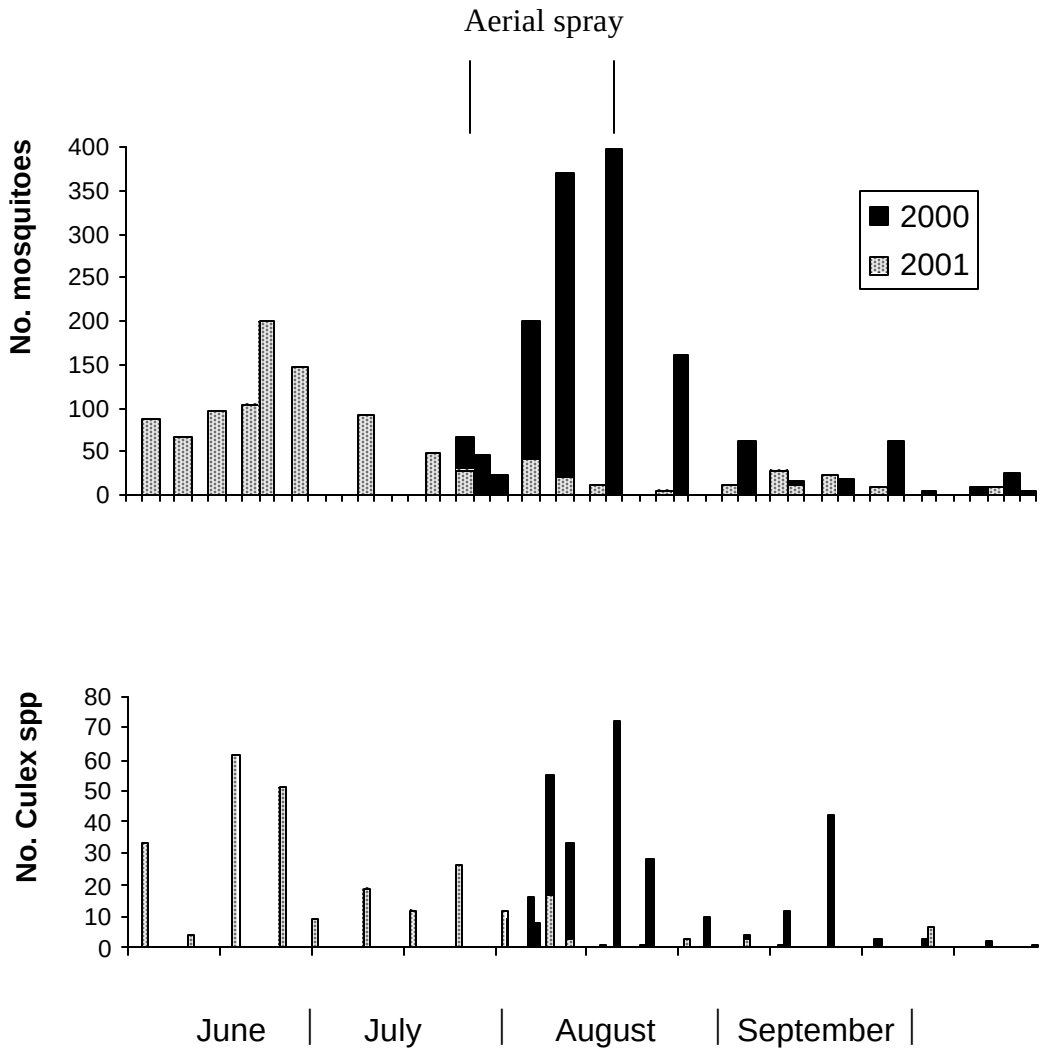


Figure 9b. Effect of insecticide aerosols, applied in 2000, on the density of mosquitoes in the Horse community in Suffolk County.

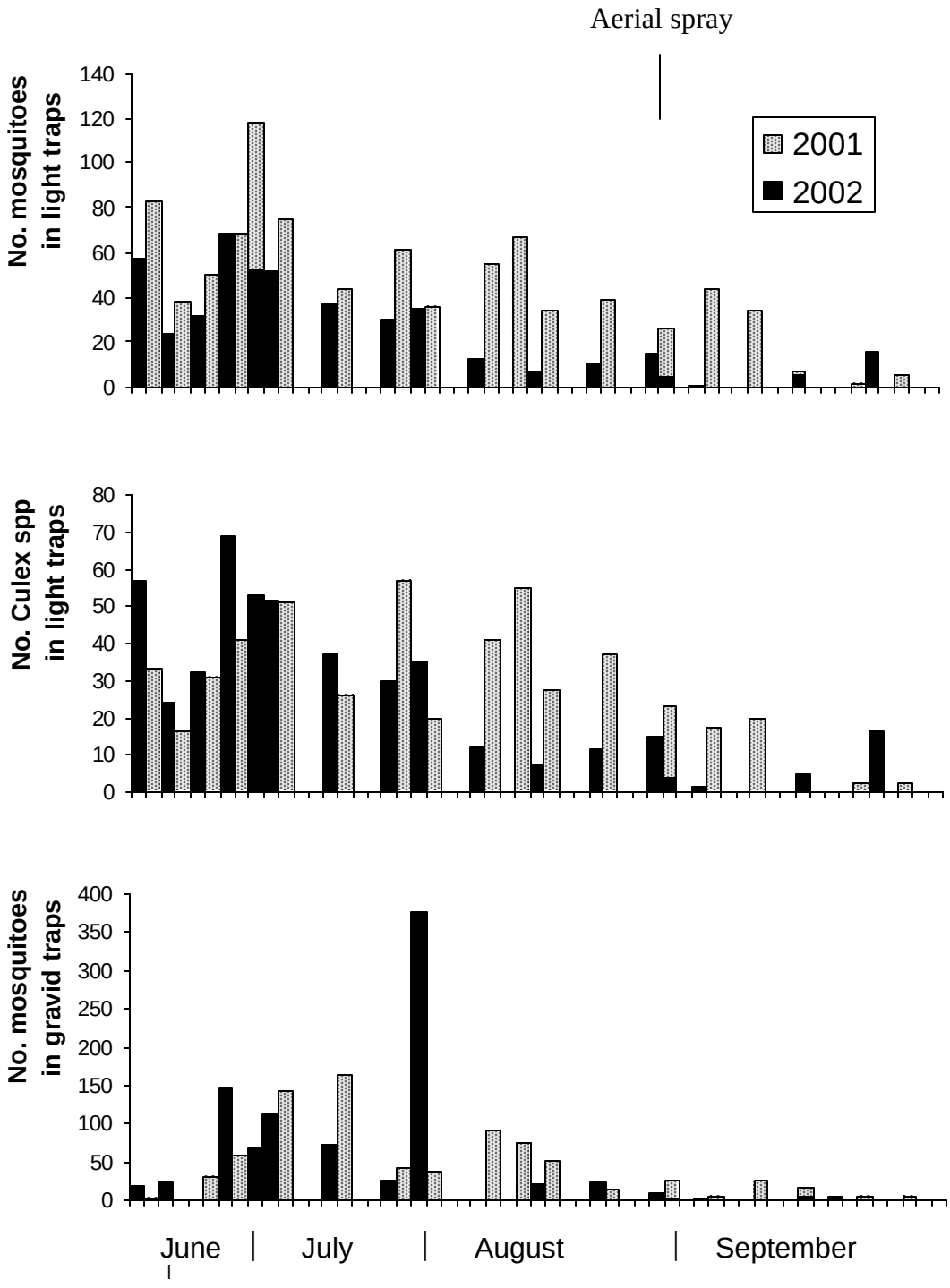


Figure 9c. Effect of insecticide aerosols, applied in 2002, on the density of mosquitoes in the Calhoun community in Suffolk County.

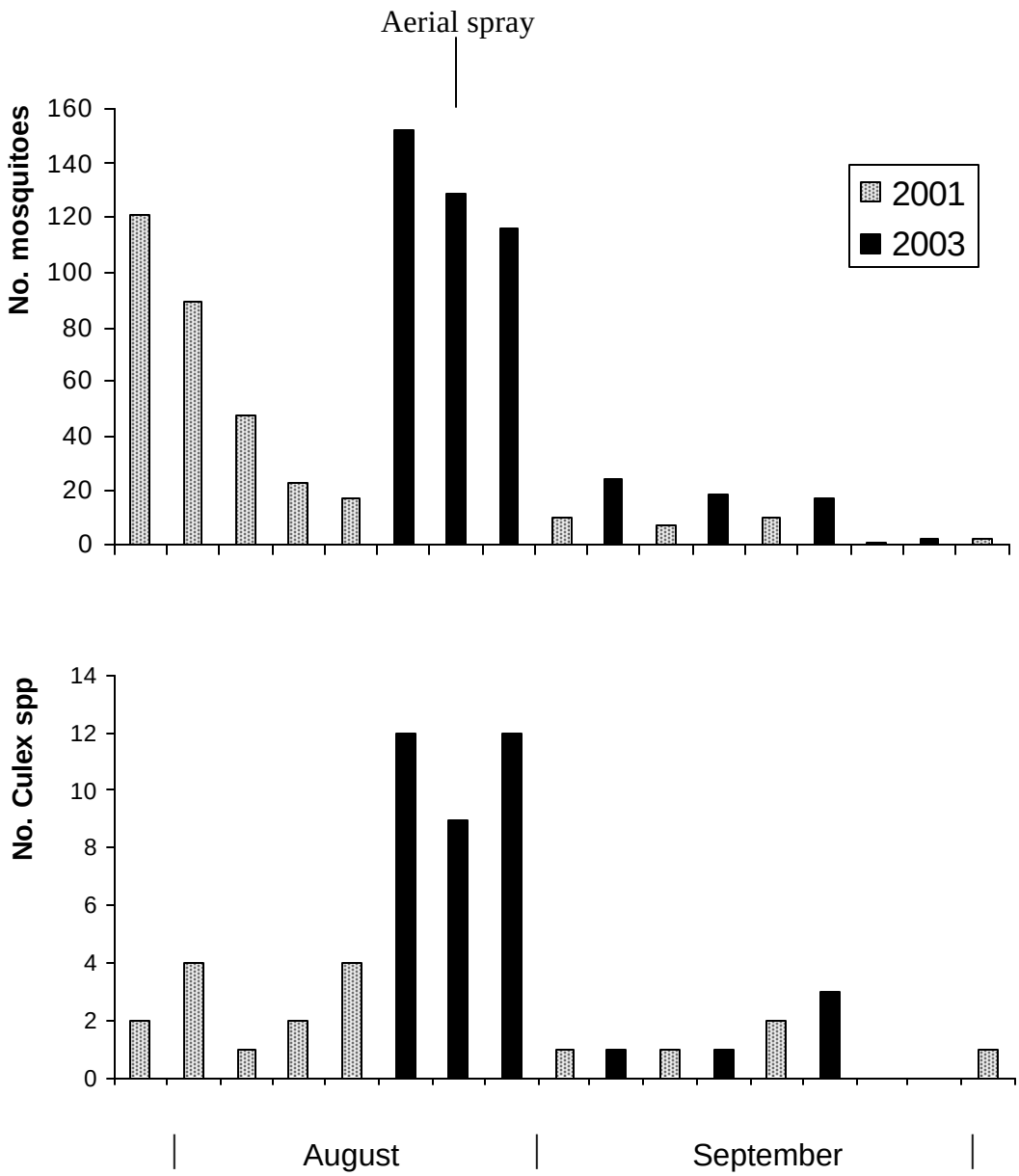


Figure 9d. Effect of insecticide aerosols, applied in 2003, on the density of mosquitoes in the Blydenburgh community in Suffolk County.

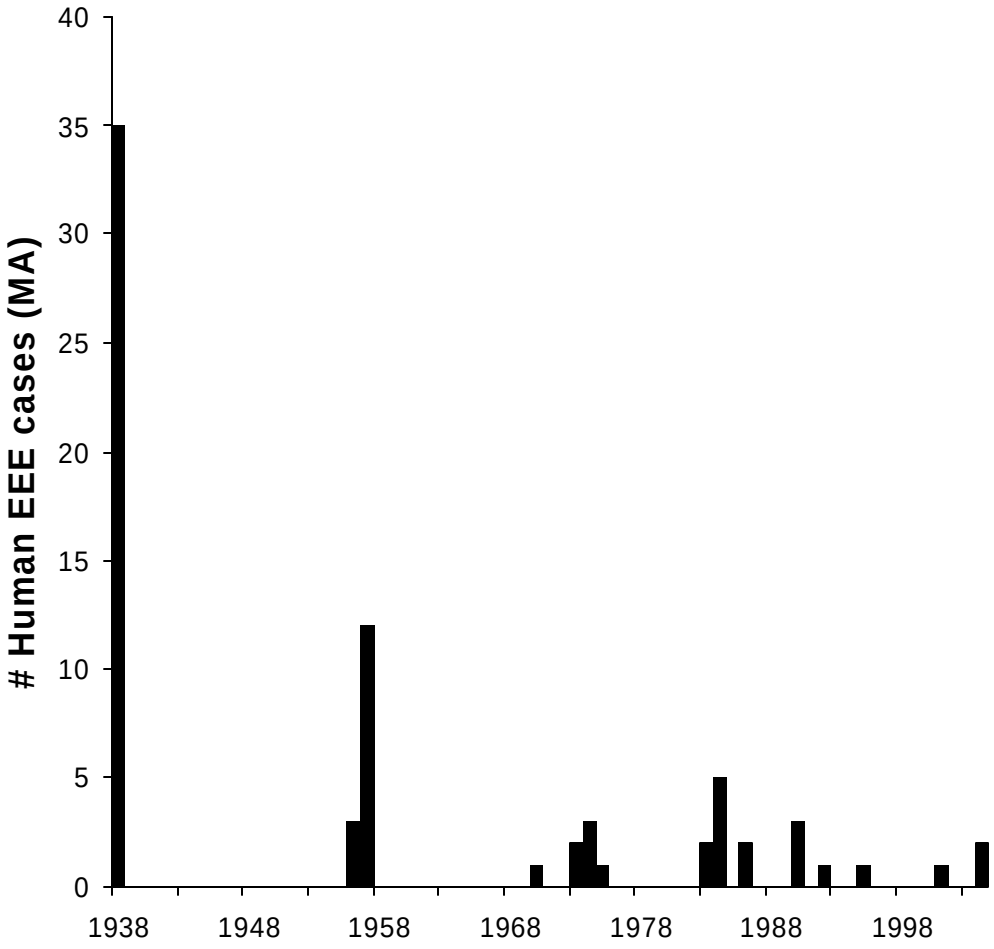


Figure 10. Frequency of human infection by EEE in Massachusetts.

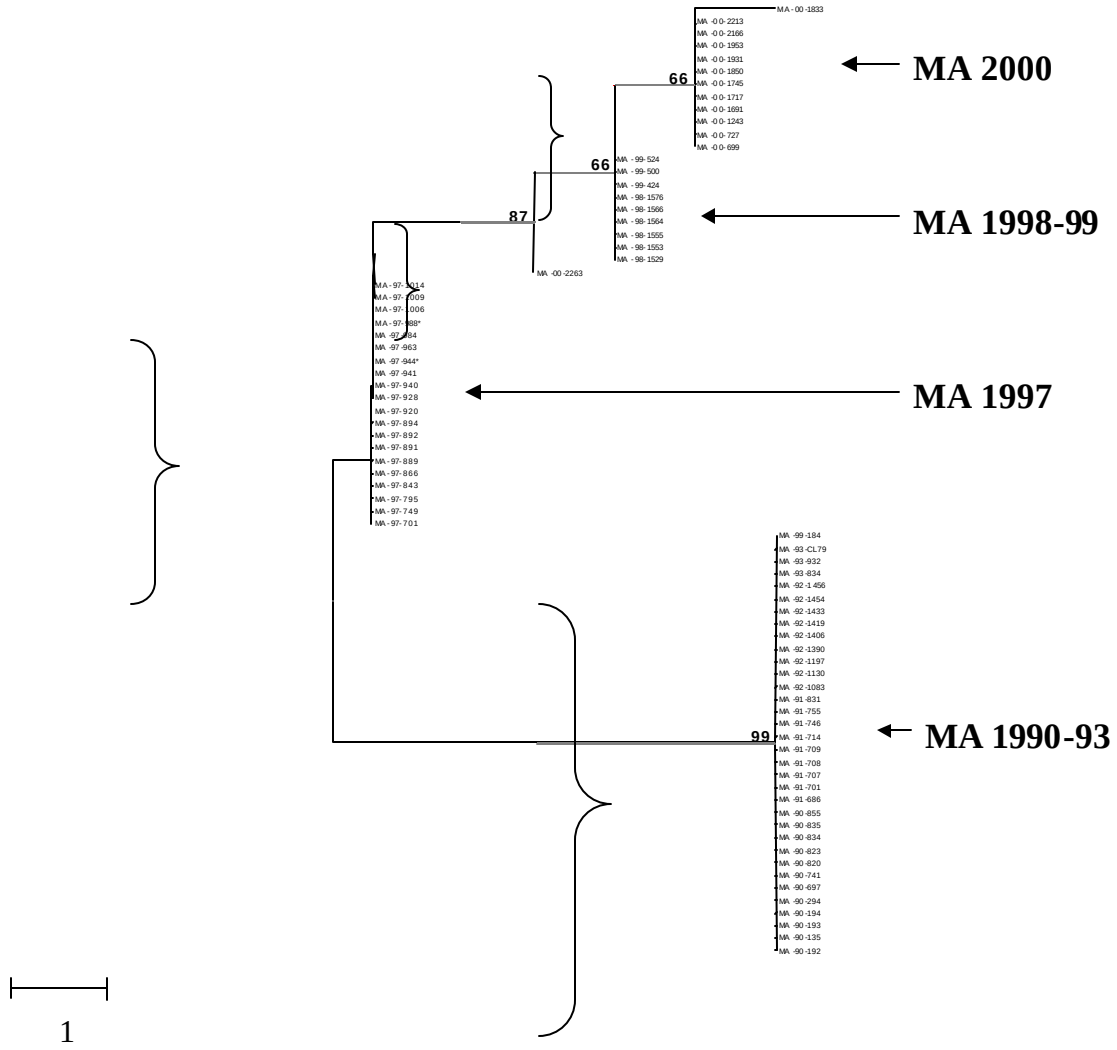


Figure 11. Maximum parsimony tree for EEE isolated in Massachusetts, based on the nsP3 amplicon, with 1000 replicate boot-strap values at nodes with more than 50% confidence.

REFERENCES

Abd el-Rahim, IH, U Abdel-Hakim, and M Hussein. 1999. An epizootic of Rift Valley fever in Egypt in 1997. Rev Sci Tech. 18:741-8.

Anderson, RM and RM May. 1991. Infectious diseases of humans: dynamics and control. Oxford U. Press, NY.

Andreadis, TG, PM Capotosto, RE Shope, and SJ Tirrell. 1994. Mosquito and arbovirus surveillance in Connecticut, 1991-1992. J Am Mosq Control Assoc 10:556-64.

Anderson, JF, TG Andreadis, AJ Main, and DL Kline. 2004. Prevalence of West Nile virus in tree canopy-inhabiting Culex pipiens and associated mosquitoes. Am J Trop Med Hyg 71:112-119.

Anonymous. 1902. Reports on Mosquitoes with map. North Shore Improvement Association. 124 pp.

Annonymous. 1995. Workshop on the geographic spread of Aedes albopictus in Europe and the concern among public health authorities. Proceedings of a workshop held at the Istituto Superiore di Sanita, Rome, Italy, 19-20 December 1994. Parassitologia 37:87-90.

Annonymous. 2000. Probable locally acquired mosquito-transmitted Plasmodium vivax infection--Suffolk County, New York, 1999. MMWR Morb Mortal Wkly Rep. 49:495-8.

Asnis, DS, R C Donetta, AA Teixeira, G Waldman, and BA Sampson. 2000. The West Nile virus outbreak of 1999 in New York: the Flushing Hospital experience. Clin Infect Dis 30:413-418.

Awerbuch, TE and A Spielman. 1994. Host density and tick dynamics: the case of the vector of Lyme disease. In Modelling Vector-Borne and Other Parasitic Diseases, BD Perry and JW Hansen, eds. The International Laboratory for Research on Animal Disease. pp. 51-65.

Balkhy, HH and JR Schreiber. 2000. Severe La Crosse encephalitis with significant neurologic sequelae. Pediatr Infect Dis J 19:77-80.

Barat, LM, JR Zucker, AM Barber, ME Parise, LA Paxton, JM Roberts, and CC Campbell. 1997. Malaria surveillance--United States, 1993. MMWR CDC Surveill Summ 46:27-47.

Barrett, AD and TP Monath. 2003. Epidemiology and ecology of yellow fever virus. Adv Virus Res 61:291-315.

Black, JA. 1996. The antiquity of the Pine Barrens. Long Island Forum. Summer 1996. pp 12-17.

Boromisa, RD and PR Grimstad. 1987. Seroconversion rates to Jamestown Canyon virus among six populations of white-tailed deer (Odocoileus virginianus) in Indiana. J Wildl Dis 23:23-33.

Brault, AC, AM Powers, CL Chavez, RN Lopez, MF Cachon, and LF Gutierrez. 1999. Genetic and antigenic diversity among eastern equine encephalitis viruses from North, Central, and South America. Am J Trop Med Hyg 61:579-86.

Buckley, A, A Dawson, SR Moss, SA Hinsley, PE Bellamy, and EA Gould. 2003. Serological evidence of West Nile virus, Usutu virus and Sindbis virus infection of birds in the UK. J Gen Virol 84:2807-17.

Chvala, S, J Kolodziejek, N Nowotny, and H Weissenboeck. 2004. Pathology and Viral Distribution in Fatal Usutu Virus Infections of Birds from the 2001 and 2002 Outbreaks in Austria. Jour Comp Pathol 131:176 -- 185.

Cronon, W. 1983. Changes in the Land: Indians, Colonists, and the Ecology of New England. New York: Hill and Wang.

Ebel, GD, I Foppa, A Spielman, and SR Telford III. 1999. A focus of deer tick virus transmission in the north-central United States. Emerg. Infect. Dis 5:570-574.

Ebel, G, E Campell, H Goethert, A Spielman, and S Telford. 2000. Enzootic Transmission of Deer Tick Virus in New England and Wisconsin Sites. Am. J. Trop. Med and Hyg 63:36-42.

Erwin, PC, TF Jones, RR Gerhardt, SK Halford, AB Smith, LE Patterson, KL Gottfried, KL Burkhalter, RS Nasci, and W Schaffner. 2002. La Crosse encephalitis in Eastern Tennessee: clinical, environmental, and entomological characteristics from a blinded cohort study. Am J Epidemiol 155:1060-5.

Freeman, J, KF Laserson, I Petralanda, and A Spielman. 1999. Effect of chemotherapy on malaria transmission among Yanomami Amerindians: simulated consequences of placebo treatment. Am J Trop Med & Hyg 60:774-780.

Foster, DR. 1999. Thoreau's Country: Journey Through a Transformed Landscape. Harvard University Press

Gerdes, GH. 2002. Rift valley fever. Vet Clin North Am Food Anim Pract 18:549-55.

Gerhardt, RR, KL Gottfried, CS Apperson, BS Davis, PC Erwin, AB Smith, NA Panella, EE Powell, and RS Nasci. 2001. First isolation of La Crosse virus from naturally infected Aedes albopictus. Emerg Infect Dis 7:807-11.

Glasgow, D, N Taylor, and AG Richards. YEAR ??? Mosquitoes and wildlife as interrelated problems in human ecology; a preliminary report on the salt marsh vegetation of Long Island, New York; Mosquitoes and mosquito control on Long Island, New York, with particular reference to the salt marsh problem. Bull NY State Museum 316:1-185.

Grimstad, PR, CH Calisher, RN Harroff, and BB Wentworth. 1986. Jamestown Canyon virus (California serogroup) is the etiologic agent of widespread infection in Michigan humans. Am J Trop Med Hyg 35:376-86.

Grimstad, PR, DG Williams, and SM Schmitt. 1987. Infection of white-tailed deer (Odocoileus virginianus) in Michigan with Jamestown Canyon virus (California serogroup) and the importance of maternal antibody in viral maintenance. J Wildl Dis 23:12-22.

Hodgson, J, A Spielman, N Komar, G Krahforst, and R Pollack. 2001. Interrupted Blood-Feeding by Culiseta melanura (Diptera: Culicidae) on European starlings. Entom Soc Amer. 38:59-66.

Johansen, CA, DJ Nisbet, P Zborowski, AF van den Hurk, SA Ritchie, and JS Mackenzie. 2003. Flavivirus isolations from mosquitoes collected from western Cape York Peninsula, Australia, 1999-2000. J Am Mosq Control Assoc 19:392-6.

Kambili, C, HW Murray, and LM Golightly. 2004. Malaria: 30 years of experience at a New York City teaching hospital. Am J Trop Med Hyg 70:408-11.

Kiszewski, AE and A Spielman. 1993. Ticks on a changing landscape. Mass Wildlife 43:18-27.

Kitron, U, J Michael, J Swanson, and L Haramis. 1997. Spatial analysis of the distribution of LaCrosse encephalitis in Illinois, using a geographic information system and local and global spatial statistics. Am J Trop Med Hyg 57:469-75.

Kitron, U, J Swanson, M Crandell, PJ Sullivan, J Anderson, R Garro, LD Haramis, and PR Grimstad. 1998. Introduction of Aedes albopictus into a La Crosse virus--enzootic site in Illinois. Emerg Infect Dis 4:627-30.

Komar, N, DJ Dohm, MJ Turell, and A Spielman. 1999. Eastern equine encephalitis virus in birds: relative competence of European Starlings (Sturnus vulgaris). Am J Trop Med Hyg 60:387-391.

Komar, N and A Spielman. 1994. Emergence of eastern encephalitis in Massachusetts. Ann N Y Acad Sci 740:157-68.

Komar, N. 2004. West Nile virus: epidemiology and ecology in North America. Adv Virus Res 61:185-235.

Laserson, KF, I Petraland, R Almera, RH Barker Jr, A Spielman, JH Maguire, and DW Wirth. 1999. Genetic characterization of an epidemic of Plasmodium falciparum malaria among Yanomami Amerindians. J Infect Diseases 180:2081-2085.

Laserson, K, D Wypu, I Petralanda, A Spielman, and J Maguire. 1999. Differential pertetuation of malaria species among Amazonian Yanomami Amerindians. Amer J Trop Med Hyg 60:767-773.

Layton, M, ME Parise, CC Campbell, R Advani, JD Sexton, EM Bosler, and JR Zucker. 1995. Mosquito-transmitted malaria in New York City, 1993. Lancet 346:729-31.

Lundstrom, JO. 1999. Mosquito-borne viruses in western Europe: a review. J Vector Ecol. 24:1-39.

Marshall, WF, SR Telford III, and PN Rhys PN. 1994. Detection of Borrelia burgdorferi DNA in museum specimens of Peromyscus leucopus. J. Infect. Dis. 170: 1027-1032.

Malkinson, M, Y Weisman, S Pokamonski, R King, and V Deubel. 2001. Intercontinental transmission of West Nile virus by migrating white storks. Emerg Infect Dis. 7:540.

Madani, TA, YY Al-Mazrou, MH Al-Jeffri, AA Mishkhas, AM Al-Rabeah, AM Turkistani, MO Al-Sayed, AA Abodahish, AS Khan, TG Ksiazek, and O Shobokshi. 2004. Rift Valley fever epidemic in Saudi Arabia: epidemiological, clinical, and laboratory characteristics. Clin Infect Dis. 38:1503.

Mather, TN, JMC Ribeiro, and A Spielman. 1987. Lyme disease and babesiosis: acaricide focused on potentially infected ticks. Am. J. Trop. Med. Hyg. 36: 609-614.

Matuschka, FR, R Allgower, A Spielman, and D Richter. 1999. Characteristics of garden dormice that contribute to their capacity as reservoirs of Lyme disease spirochetes. Appl and Env Microbiol 65:707-711.

McJunkin, JE, EC de los Reyes, JE Irazuzta, MJ Caceres, RR Khan, LL Minnich, KD Fu, GD Lovett, T Tsai, and A Thompson. 2001. La Crosse encephalitis in children. N Engl J Med 345:148-9.

Miller, JR. 2001. The control of mosquito-borne diseases in New York City. J Urban Health 78:359-66.

Mores, CN, SM Rich, and A Spielman. 2002. Interepidemic Persistence of Eastern Equine Encephalomyelitis Virus Variants Where Winters are Severe. In prep.

Motashari, F, I Poshni, EM Layton, D Graham, C Bradley, M Kacacia, S Wong, C Franchell, D Morse, B Wallace, P Smith, E Bresnitz, C Baisley, A Iton, G Archambault, D Mayo, J Hadler, and EIS officers, CDC. 2001. Serosurveys for West Nile infection – New York and Connecticut counties. Morbidity and Mortality Weekly Report 50:37-39.

Murphy, J. 2003. An American Plague: the true and terrifying story of the yellow fever epidemic of 1793. Clarion Books. 165 pp.

Neitzel, DF and PR Grimstad. 1991. Serological evidence of California group and Cache Valley virus infection in Minnesota white-tailed deer. J Wildl Dis 27:230-7.

Pollack, RJ and L Marcus. 2005. A travel medicine guide to arthropods of medical importance. *Infectious Disease Clinics of North America* 19(1):169-183.

Poshni, I, EM Layton, D Graham, C Bradley, M Kacacia, S Wong, Franchell, D Morse, B Wallace, P Smith, E Bresnitz, C Baisley, A Iton, G Archambault, D Mayo, J Hadler, and EIS officers, CDC.. 2001. Serosurveys for West Nile infection – New York and Connecticut counties, 2000. Morbidity and Mortality Weekly 50:37-39.

Sammels, LM. 1999. Geographic distribution and evolution of Sindbis virus in Australia. Journal of General Virology 80:739-748.

Sardelis, MR, MJ Turell, and RG Andre. 2002 Laboratory transmission of La Crosse virus by Ochlerotatus j. japonicus (Diptera: Culicidae). J Med Entomol 39:635-9.

Severinghaus, CW and CP Brown. 1956. History of the white-tailed deer in New York. NY Fish Game Jour 3:129-167.

Smith, JB. 1904. Report of the New Jersey State Agricultural Experiment Station within the State, their habits, life history, etc. MacCrellish and Quigly, Trenton NJ. 472 pp.

Spielman, A and PA Rossignol. 1984. Insect vectors. in Warren, K.S. and A.A.F. Mahmoud (eds.) Tropical and Geographical Medicine. McGraw-Hill, N.Y. pp.167-183.

Spielman, A. 2001. Structure and Seasonality of Nearctic Culex pipiens populations. Ann NY Acad Sci. 957: 220-234.

Steere, AC, SE Malawista, and DR Snydman. 1976. Lyme arthritis: an epidemic of oligoarticular arthritis in children and adults in three Connecticut communities. Arthritis and Rheumatism 20: 7-17.

Steere, AC, VJ Sikand, F Meurice, DL Parenti, E Fikrig, RT Schoen, J Nowakowski, and CH Schmid. 1998. Vaccination against Lyme disease with recombinant Borrelia burgdorferi outer surface lipoprotein A with adjuvant. NEJM 339:209-215.

Tyzzer, EE. 1938. Cytoecetes microti, n.g., n.sp., a parasite developing in granulocytes and infective for small rodents. Parasitol. 30: 242-257.

Utz, JT, CS Apperson, JN MacCormack, M Salyers, EJ Dietz, and JT McPherson. 2003. Economic and social impacts of La Crosse encephalitis in western North Carolina. Am J Trop Med Hyg 69:509-18.

Villari, P, A Spielman, N Komar, M McDowell, and R Timperi. 1995. The economic burden imposed by a residual case of eastern encephalitis. Am J Trop Med Hyg 52:8-13.

Wilson, ML. 1994. Rift Valley fever virus ecology and the epidemiology of disease emergence. Ann N Y Acad Sci 740:169-80.

Wilson, ML, JF Levine, and A Spielman. 1984. Effect of deer reduction on abundance of the deer tick (Ixodes dammini). Yale J Biol Med 57:697-705.

Zamparo, JM, TG Andreadis, RE Shope, and SJ Tirrell. 1997. Serologic evidence of Jamestown Canyon virus infection in white-tailed deer populations from Connecticut. J Wildl Dis 33:623-7.