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The Control of Mosquito-Borne Diseases in New York City

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ABSTRACT *Mosquito control began in New York City in 1901. Large-scale efforts to drain marshlands occurred through the 1930s, and aerial application of pesticide occurred as early as 1956. Components of early mosquito-borne disease control were reimplemented in 1999–2000 in response to an outbreak of West Nile virus, and included promoting public and health professional awareness regarding disease causation and prevention, providing free government laboratory testing, case reporting, mapping of mosquito breeding sites and their elimination or application of larvicide to them, and adult mosquito control. Because a potential for various mosquito-borne diseases in New York City persists, continued efforts are warranted to limit mosquito breeding, to monitor adult mosquito populations for the presence of human pathogens, and to establish protocols and capacity for adult mosquito control.*

KEYWORDS *Malaria, Mosquito Control, New York City, West Nile Virus.*

Mosquitoes are significant to people as vectors of disease and when their large numbers and frequent biting disrupt daily life. Efforts to control mosquitoes can be directed at the immature stages in the mosquito's life cycle (i.e., egg, larva, pupa) and at adult mosquitoes. Immature mosquitoes live exclusively in water (some mosquito species lay their eggs on moist soil, but require water for the eggs to hatch and develop), while adult mosquitoes are widely dispersed throughout the environment, both indoors and out.

Deliberate efforts to control mosquitoes in New York City began in 1901 to prevent malaria.[1] The basic elements of mosquito-borne disease control implemented in New York City began in 1901: promoting public and health professional awareness regarding disease causation and prevention, establishing government laboratory testing capacity, reporting cases of suspected mosquito-borne disease to the New York City Department of Health, and mapping and eliminating or applying larvicide to natural and artificial mosquito breeding sites. The elements were reimplemented in 1999, following an outbreak of West Nile virus in New York City. The control of adult mosquitoes by aerial pesticide application, a visible part of the city's effort in 1999, occurred in New York City as early as 1956 in response to public complaints regarding large numbers of biting mosquitoes.

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EARLY HISTORY

The essential role of *Anopheles* mosquitoes in transmitting malaria, in contrast with theories of disease causation by "unhealthy vapors,"[2] was reported by Ross[3] in 1899. In 1900, 216 persons died from "malarial fevers" in New York City.[4] A New York City Board of Health resolution of July 18, 1901, ordered that mosquito breeding places, including "surface rain-water pools and surface stagnant water" and "pails or tubs of standing water," be eliminated or treated with oil to prevent mosquito breeding; required health care institutions and requested physicians to report cases of malaria to the Department of Health (supported by provision of postal cards by the Department of Health); and directed that information regarding the causes and prevention of malaria be mailed to patients and their physicians.[5] In 1902, the Department of Health laboratory was made available at no cost for the microscopic examination of a patient's blood for the presence of malaria, and Department of Health sanitary inspectors began mapping potential mosquito breeding places, eliminating them when feasible or applying larvicide in the form of oil to coat the water's surface.[6] In 1903, the Department of Health sent every New York City physician a booklet regarding the prevention and treatment of malaria.[7] By 1904, New York City was home to the National Mosquito Extermination Society, which held its second annual convention[8] in New York City on December 15–16, 1904, and which advocated "extermination [of mosquitoes] by systematic private and public operations."[9] By 1906, the number of deaths in New York City due to malaria dropped to 7, due in part to improved laboratory diagnosis, which classified 4 additional deaths as due to other causes.[10]

Early efforts to reduce mosquito breeding focused on the elimination and ditching of wetlands. The filling in of wetlands deprived mosquitoes of a breeding place. Ditching provided drainage to prevent fresh water from accumulating, and in tidal areas, ditching permitted a twice-daily opportunity for fish to enter the ditches and eat mosquito larvae that were present. The city's sanitary code[11] (section 272) and charter (section 1197) were amended to require property owners and managers to eliminate breeding sites or to apply larvicide; failure to act enabled the Department of Health to conduct the work and to place a lien on the property.[12(p15)] Instances of this early effort included the partial filling of Coney Island Creek (a tidal stream that once separated Coney Island from the "mainland" of Brooklyn and that changed Coney Island into a peninsula[8]), as well as drainage in the Bronx (e.g., Pelham Bay) and Queens (e.g., Bayside, Douglaston, Little Neck).[12(p15)] By 1913, 1625 miles of ditches had been constructed and drainage established for more than 36 square miles (i.e., more than 10% of New York City's surface area).[12(p16)] Early mosquito control practitioners took credit for making habitable new areas of the rapidly expanding city that had been previously considered uninhabitable due, in part, to large numbers of biting mosquitoes.[12(p17)]

During the depression in the 1930s, the construction and maintenance of ditches expanded with the support of the Works Progress Administration (WPA). In 1935, approximately 3,000 workers were engaged in eliminating nearly 2,000 ponds, maintaining 3,200 miles of drainage ditches, and applying larvicide to 70,000 catch basins and thousands of freshwater wetlands.[13] The WPA also conducted an entomologic survey of New York City in 1935–1936 that documented the presence of 26 mosquito species.[14] Malaria transmission throughout the United States, including New York City, was largely eliminated by the 1940s.[15]

In the 1950s, the purpose of adult and larval mosquito control in New York

City no longer included disease prevention and had shifted to reducing the large number of biting mosquitoes,[16(p143)] found primarily in coastal areas of Queens, Brooklyn, Staten Island, and the Bronx. In 1956, the Department of Health initiated aerial and ground spraying of pesticides[16(p143–145)]; as early as 1957, helicopters were employed.[17] The use of pesticides directed against adult mosquitoes declined sharply in 1982 following a reduction in state aid,[18] although the application of larvicide[19] continued into the 1990s.

REEMERGENCE OF MOSQUITO-BORNE DISEASES IN NEW YORK CITY IN THE 1990s

For approximately 50 years (from the 1940s to the 1990s), there was no recognized local transmission of mosquito-borne disease in New York City. In 1955, a global campaign to eradicate malaria began[20]; it was sustained until the late 1960s, when efforts were scaled back.[21] Malaria subsequently increased in many parts of the world, and with growing international travel and immigration, an increasing number of persons arrived in New York City with active malaria.[22] The average number of persons diagnosed annually with malaria in New York City increased from 57 (1979–1983) to 229 (1994–1998).[23]

Three cases of malaria (2 probable, 1 possible) occurred in New York City in 1993 among persons without recent international travel or other risk factors for malaria.[24] All 3 people affected resided in the same neighborhood of Queens and had their onset of symptoms within 2 days of one another. Their infections were most likely the result of bites by a mosquito(es) that had become infected in New York City by taking blood from a person(s) that was parasitemic after returning from an endemic area. In addition to this 1993 locally acquired malaria outbreak in New York City, there have been similar clusters in New Jersey[25] (1991) and Suffolk County, New York[26] (1999).

Citywide adult and larval mosquito control in New York City was resumed in 1999 in response to an outbreak of West Nile virus. The first outbreak of West Nile virus in the Western Hemisphere occurred in the greater New York City area during the summer of 1999, resulting in 59 seriously ill people, including 7 deaths, and including additional deaths among horses, wild and exotic zoo birds, and a cat. In addition to serious illness, a serosurvey in northern Queens determined that about 1 in 40 persons (2.6%) had antibodies to West Nile virus due to recent infection.[27] Approximately one half of the human survivors from the 1999 outbreak showed residual neurologic and neuromuscular disability 6 months after infection (D. Nash and A. Labowitz, unpublished data, January 2001). There was initial uncertainty regarding whether the outbreak was mosquito borne and then as to which mosquito-borne virus was responsible.[28] All areas of New York City were treated at least twice in 1999 with pesticide sprayed by helicopters and trucks and directed against adult mosquitoes. Larval mosquito control was conducted at sewage plants and unused swimming pools where mosquito breeding was found. Adult mosquitoes were trapped, and at least 9 groups (or pools) of *Culex* mosquitoes (*Culex pipiens* was the only species identified) from New York City tested positive for West Nile virus.

In retrospect, one can observe that the onset of new human cases due to West Nile virus infection peaked during the week of August 22–28 (with exposure to mosquitoes infected with West Nile virus presumably occurring 3–14 days prior to onset), and new case onsets had begun to decline by the time pesticide application

commenced in early September. But, as pesticide application was initiated and expanded, the Department of Health was in the early stages of receiving hundreds of clinical specimens for West Nile virus testing. These specimens were submitted by physicians in response to active Department of Health solicitation of case reports of encephalitis and meningitis. While the majority of these specimens tested negative for West Nile virus, laboratory confirmation of mosquito-borne infection in Queens and Bronx residents preceded the decisions to initiate pesticide application in Queens and to extend pesticide application to the Bronx. Laboratory confirmation of mosquito-borne infection in a Brooklyn resident preceded the decision to extend pesticide application citywide.

The persistence of West Nile virus in the greater New York City area during the winter of 1999–2000 was detected in overwintering adult *Culex pipiens* mosquitoes in Queens[29] and in a Cooper's hawk in Westchester County.[30] Programs to collect and test dead and live wild birds, sentinel chickens, and adult mosquitoes were established by spring 2000, with the intent of detecting the presence of West Nile virus in New York City before human cases occurred. The public was asked to report dead birds to the Department of Health Web site and hot line.

Larval mosquito control, using bacterial and insect growth-regulating products, was initiated citywide in April 2000 and included more than 150,000 storm drains and natural wetlands and the expanded use of fish that eat mosquito larvae (i.e., *Gambusia affinis*) at sewage treatment plants. A public education campaign encouraged residential and commercial property owners to eliminate or treat with larvicide any potential mosquito breeding sites. A Board of Health resolution was published, restating that standing water favors mosquito breeding and is a public health nuisance; this resolution enabled the Department of Health to access private property immediately to apply larvicide. The public was asked to report standing water to the Department of Health Web site and hot line. Mapping of larval breeding sites and citywide applications of larvicide continued through the spring, summer, and fall.

The first bird infected with West Nile virus in 2000 in New York City was reported on July 16. The Staten Island bird had been found dead on July 5, and mosquitoes collected on Staten Island on July 7 were reported on July 24 to be positive for West Nile virus. Truck spraying of pesticide commenced on Staten Island on the night of July 19 in an approximate 2-mile radius around where each of two birds infected with West Nile virus had been found, consistent with recommendations from the Centers for Disease Control and Prevention.[31] Additional detections of West Nile virus in birds and mosquitoes led to pesticide application to the remainder of Staten Island on July 24 and repeated islandwide applications by truck on the nights of August 2 and 14. Islandwide pesticide spraying by both truck and helicopter (in areas with limited roads) occurred on the nights of August 17, 27, 30, and September 17. To supplement ongoing hand and backpack application of larvicide, helicopter application of larvicide in large natural wetlands of Staten Island occurred on August 14. Pesticide application by truck occurred in all five boroughs of New York City following the detection of West Nile virus in birds and/or mosquitoes. During 2000, there were 14 serious human infections (1 fatal) in New York City and 6 human cases (1 fatal) in New Jersey. In addition, 177 birds, 170 mosquito pools, 10 horses, 3 squirrels, 1 raccoon, and 1 rabbit from New York City tested positive for West Nile virus in 2000, with the majority of positive findings on Staten Island. A serosurvey throughout Staten Island detected 0.5% seroprevalence,[32] indicating that approximately 1,574 people aged 12 years

and older were infected with West Nile virus on Staten Island in 2000. Outside New York City in 2000, West Nile virus expanded beyond the four states of the 1999 outbreak (i.e., Connecticut, Maryland, New Jersey, and New York) to include the District of Columbia and eight additional states (i.e., Delaware, Massachusetts, New Hampshire, North Carolina, Pennsylvania, Rhode Island, Vermont, and Virginia).[33] Serious human illness was reported from New Jersey, and serious equine illness cases occurred in Connecticut, Delaware, Massachusetts, New Jersey, Pennsylvania, and Rhode Island.[33] In 2000, mosquito species infected with West Nile virus in New York City expanded beyond *Culex pipiens* to include *Culex salinarius, Aedes cantator, Aedes triseriatus, Aedes vexans, Anopheles punctipennis*, and *Psorophora ferox*.[33]

OTHER POTENTIAL MOSQUITO-BORNE INFECTIONS IN NEW YORK CITY

In addition to malaria and West Nile virus, a risk of other mosquito-borne diseases exists in New York City. Since 1990, human cases of eastern equine encephalitis (EEE), St. Louis encephalitis (SLE), and California encephalitis (CE), including La-Crosse (LAC) encephalitis, have been documented in northeastern and midwestern states. In 1992 and 1997, human infections with EEE virus occurred in Massachusetts,[34,35] and in 2000, EEE virus was isolated from mosquitoes in Boston.[36] In 1993, a fatal human case of EEE occurred in Rhode Island[37]; in Michigan, 2 cases[37] (1 fatal) of EEE occurred in 1993, and in 1997, a nonfatal case occurred.[35] There is an overall mortality of 30% in cases of EEE.[38] Two human cases of St. Louis encephalitis occurred in 1993 in Illinois.[37] In 1993, 17 human cases of CE occurred in Wisconsin, 6 cases in Ohio, 2 cases in Illinois, and 1 case in Indiana[37]; in 1994, 14 cases of CE occurred in Ohio, 7 cases in Wisconsin, and 6 cases in Illinois.[39] In 1996, 20 human cases of LAC encephalitis occurred in Ohio, 13 cases in Illinois, 8 cases in Wisconsin, and 3 cases in Indiana. In 1997, 13 cases of LAC encephalitis occurred in Ohio, 8 cases in Wisconsin, 3 cases in Illinois, and 1 case in Indiana.[40]

Apart from mosquito-borne diseases already documented in the New York City area, changes in mosquito biology, possibly in response to global warming,[41] may introduce new mosquito-borne infections. During 2000, two mosquito species were recognized for the first time in New York City: *Aedes japonicus* (D. Fish, telephone communication, August 2000) and *Aedes albopictus* (V. Kulasekera, written communication, September 2000). LaCrosse and Jamestown Canyon viruses (K. Gottfried, telephone communication, January 2001), as well as Cache Valley and EEE viruses, have been detected in *Aedes albopictus* mosquitoes within the United States.[42] The presence of *Aedes albopictus* also creates the possibility for local transmission of dengue in New York City, involving a viremic traveler returning from an area endemic for dengue.[43]

CONCLUSION

The threat of mosquito-borne disease will persist in New York City for the foreseeable future, and a sustained mosquito-borne disease surveillance and control effort will be needed. The goals of mosquito-borne disease surveillance will be to detect pathogenic organisms (in mosquitoes, birds, and/or other animals) before human illness occurs; to warn the public and notify health care professionals when a threat to human health exists; and to be prepared to control adult mosquitoes. In addition

to surveillance, the elimination of standing water (where appropriate) and application of larvicide or introduction of mosquito-eating fish (in areas of standing water capable of breeding mosquitoes, but not suited for elimination) to reduce the immature stages of those mosquito species that are vectors of West Nile virus and malaria appear warranted. Further research is needed to define better surveillance criteria that signal a threat of human illness and thus a need for adult mosquito control, the most effective means of mosquito control in New York City's urban setting, and any potential environmental and human health effects of pesticide use. Finally, those neighborhoods in which mosquito density and frequent mosquito bites are considered a serious disruption to daily life can be offered options to reduce the population of adult mosquitoes.

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