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A GEOSPATIAL STUDY OF THE POTENTIAL OF TWO EXOTIC SPECIES OF MOSQUITOES TO IMPACT THE EPIDEMIOLOGY OF WEST NILE VIRUS IN MARYLAND[1]

FREDERICK W. KUTZ,[2,3] TIMOTHY G. WADE[4] AND BENEDICT B. PAGAC[5]

ABSTRACT. We used geospatial techniques to study the potential impact of 2 exotic mosquitoes, *Aedes albopictus* and *Ochlerotatus japonicus japonicus*, on the epidemiology of West Nile virus in Maryland. These 2 species have established populations in Maryland over the past 15 years. Larvae of both mosquito species are found in natural and artificial water-holding cavities and containers, particularly water in tires. Therefore, we used locations of licensed tire dealers and of tire dumps scheduled for clean up as an index for potential sources of mosquito vectors. This index was expected to underestimate the actual population of source habitats. West Nile virus activity in Maryland during 1999, 2000, and 2001 was indicated by the presence of dead, infected birds, particularly American crows and other corvids; infected pools of mosquitoes; and human and horse infections. Adult females of both mosquito species are aggressive, opportunistic feeders that have been observed to take blood meals from avian and mammalian hosts. Susceptible vertebrate hosts, particularly birds, are ubiquitously distributed throughout the developed areas of the state. This analysis demonstrated a spatial convergence of the virus, the exotic mosquito vectors, and susceptible hosts. This conjunction indicated that these 2 mosquito species have a high potential to serve as bridge vectors and thus, impact the epidemiology of West Nile virus under favorable environmental and climatic conditions. Positive mosquito pools were collected from only the Baltimore–Washington metropolitan corridor, suggesting a newly created enzootic focus for this virus. Land-cover analysis of the sites where virus activity had been detected showed predominantly developed land uses. Analyses of the environmental justice aspects (social, economic, and housing characteristics) of block groups with human West Nile fever cases or with positive mosquito pools were equivocal. Human cases seemed to occur in developed block groups with lower income levels.

KEY WORDS *Aedes albopictus, Ochlerotatus japonicus japonicus,* Asian tiger mosquito, West Nile virus, epidemiology, geographic information systems, environmental justice

INTRODUCTION

Two species of mosquitoes, *Aedes albopictus* (Skuse) and *Ochlerotatus japonicus japonicus* (Theobald), recently found in Maryland may impact the epidemiology of West Nile virus (WN) as well as other vectorborne infections. The first established population of the Asian tiger mosquito, *Ae. albopictus,* in the conterminous USA was discovered in Harris County, TX, in 1985 (Sprenger and Wuithiranyagool 1986). Since 1985, permanent populations have been discovered in 26 states in the conterminous USA (Moore 1999). The Asian tiger mosquito was first reported in Maryland in 1987 in tires in the city of Baltimore (C. Lesser 2002, personal communication). The first reports of *Oc. j. japonicus* in the USA were from New Jersey and New York in 1998 (Peyton et al. 1999). This species was first reported in Maryland from Frederick County in 2000 (Sardelis and Turell 2001). Populations of this mosquito reportedly have spread rapidly to Connecticut (Andreadis et al. 2001), Ohio, Pennsylvania (Sardelis and Turell 2001), and Virginia (Sardelis et al. 2002).

Of the 2 species, the bionomics and distribution of *Ae. albopictus* in the USA are better known. The distribution and bionomics of *Oc. j. japonicus* in the USA are poorly understood. Both species feed readily on young chickens in the laboratory and are opportunistic feeders that will take blood from avian and mammalian hosts (Sardelis et al. 2002). The larval stage of both these species of mosquitoes develops in water in natural and artificial water-holding cavities and containers, especially in tires. In order to evaluate the potential for spread of these species by the tire route, we used locations of dumps containing large numbers of discarded tires and of commercial tire retail facilities licensed by the Maryland Department of the Environment (MDE) as indicators of dissemination potential. Also, discarded tires frequently are found as trash in many areas outside of the identified specific locations in this report. Therefore, our conclusions

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[2] Landscape Ecology Branch, U.S. Environmental Protection Agency, 701 Mapes Road, Fort Meade, MD 20755-5350.

[3] Retired. Corresponding address: 4967 Moonfall Way, Columbia, MD 21044.

[4] Landscape Ecology Branch, U.S. Environmental Protection Agency, Mail Code E243-05, Research Triangle Park, NC 27711.

[5] U.S. Army Center for Health Promotion and Preventive Medicine-North, Fort George G. Meade, MD 20755-5225.

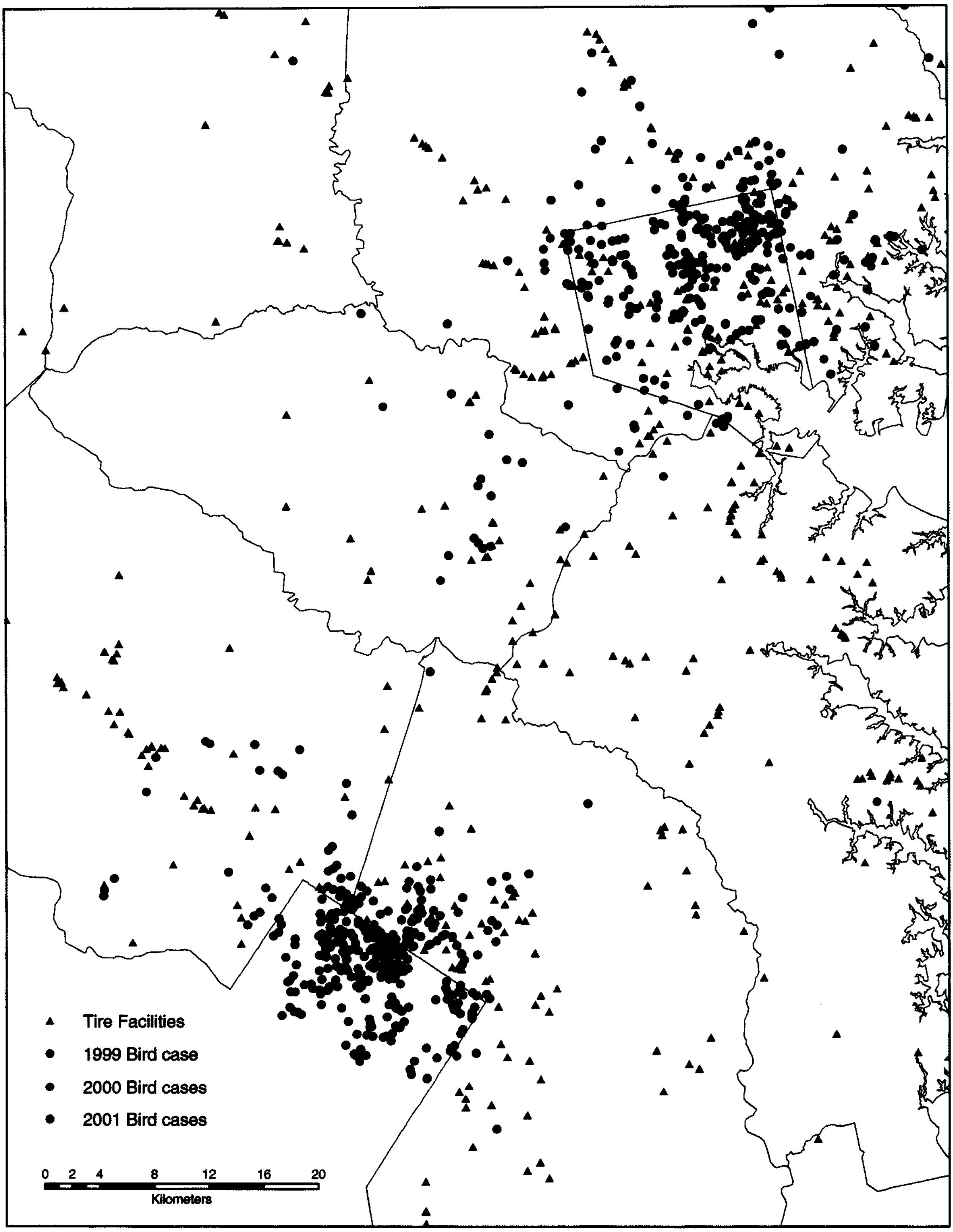

Fig. 1. Map of central Maryland showing locations of all tire facilities and dumps and of birds infected with West Nile virus, 1999–2001.

Table 1. Description of types of licenses and scrap tire clean-up sites in Maryland.

Program or license type	Description	Total number	Number georeferenced
Secondary tire collection facility	51–1,500 tires per facility at any given time	689	689
Primary tire collection facility	More than 1,500 tires at any given time	2	2
Tire recycling facility	No tire limit	2	2
Tire clean-up sites	Sites with mainly discarded tires, but also other junk	98	98

may underestimate potential for dissemination of these species.

West Nile virus activity was first reported in Maryland with the discovery of a dead infected crow in Baltimore City in 1999 (DuVernoy 2002, personal communication). As of the end of 2001, the virus has been detected in horses, humans, birds, or mosquitoes in 11 counties of the Baltimore metropolitan area and Baltimore City. Both *Ae. albopictus* and *Oc. j. japonicus* have been incriminated as efficient vectors of WN in laboratory studies (Sardelis and Turell 2001, Turell et al. 2001). In these studies, both species were highly susceptible to infection and were able to transmit virus by bite. Depending on the viral titer at the time of feeding, the estimated transmission rates for these 2 species were 2–4 times higher than for *Culex pipiens* L., the principal suspected vector in New York (CDC 1999). In 2001, 2 pools of *Ae. albopictus* collected in Baltimore City, Maryland, were positive for WN. Additionally, *Oc. j. japonicus* from New York have been found to be infected with WN (CDC 2000).

The rapid spread of these 2 exotic mosquito species across the USA has raised concern about their potential involvement in the transmission of North American arboviruses. The objective of this study was to use geographic information system (GIS) approaches to evaluate the potential impact of these 2 species of mosquitoes on the epidemiology of WN in Maryland. In order to evaluate the potential spread of these species by the tire route, we used locations of dumps containing large numbers of discarded tires and of commercial tire retail facilities licensed by the MDE as indicators of dissemination potential. These sites were geographically referenced and superimposed on data showing locations of WN activity in birds, horses, humans, and mosquito pools. Additionally, we used landscape analysis to characterize the land cover surrounding the locations where infected birds and positive mosquito pools were found. We also investigated the environmental justice aspects of the epidemiology of WN in Maryland.

Table 2. Number of tire collection facilities and clean-up sites within selected distances of birds positive for West Nile virus in Maryland by year.

Collection year	1.6-km radius	9.6-km radius	19.3-km radius
1999	5	66	176
2000	43	312	469
2001	165	439	555

MATERIALS AND METHODS

We obtained the numbers and locations of primary and secondary tire collection facilities, tire clean-up sites, and tire recycling facilities as of July 1, 2001, from the Waste Management Administration of the MDE (Maryland Department of the Environment 2001) (Fig. 1 and Table 1). Licenses for the 694 general tire collection facilities present in Maryland on July 1, 2001, were excluded because these facilities have less than 50 tires at any given time, and stock is rapidly rotated.

Tire facilities data designated locations by street address, city, and zip code. This information was used to geocode the facilities with the use of the Maryland Property View (Maryland Department of Planning 2001).

The locations of mosquito light traps augmented with CO_2 operated in 2001 by the Maryland Department of Agriculture (MDA) and by the City of Baltimore were obtained from MDA. During the mosquito season in 2001, 152 light traps were operated nightly. Collections from light traps were sorted by mosquito species by MDA personnel, and each pool was tested for WN at the laboratory of the Maryland Department of Health and Mental Hygiene. Locations of infected humans from 2001, horses from 2001, and birds from 1999, 2000, and 2001 also were provided by MDA (C. Lesser 2002, personal communication).

Land-cover/land-use data produced by the Multi-Resolution Landscape Consortium (Loveland and Shaw 1996) were obtained from the National Land Cover Database (Vogelmann and Wickham 2000, Vogelmann et al. 2001). These data were derived from Landsat Thematic Mapper and other ancillary data (Vogelmann et al. 2001) and closely follow an Anderson level II classification (Anderson et al. 1976). Spatial resolution was 30 m.

Spatial analyses were performed using ArcView 3.2 and ArcInfo 8.1 GIS software (ESRI 2002).

Table 3. Percentage of developed land cover within 1.6 km of positive mosquito pools and infected birds.

Virus host	Mean percentage of developed land cover	Minimum percentage of developed land cover	Maximum percentage of developed land cover
Positive mosquito pools (2001)	80	51	94
Infected birds (1999, 2000, and 2001)	74	>1	97
Negative mosquito pools (2001, Baltimore City only)	80	50	98
Negative mosquito pools (2001, remainder of Maryland only)	39	0	97

Proximity analysis was conducted to determine distances among tire facilities and positive mosquito pools and infected bird, human, and horse locations. A 1.6-km distance was used as the maximum likely flight distance for mosquitoes, taking into account known travel distances, wind, and possible imprecision in point locations of tire facilities. Proportions of land cover were calculated for 0.8- and 1.6-km radii around all mosquito pools and 1.6-, 9.6-, and 19.3-km radii around infected birds with the use of Analytical Tools Interface for Landscape Assessment (ATtILA), an ArcView extension produced by the U.S. Environmental Protection Agency (Donald Ebert 2002, personal communication).

Data to evaluate the environmental justice aspects of this study were from Census 2000 from the United States Census Bureau (2002). Information collected from Census 2000 was social, economic, and housing characteristics compiled from a sample of approximately 1 in 6 households in Maryland that received the Census 2000 long-form questionnaire. The major analyses used to examine the environmental justice aspects of this study were comparisons of data from block groups to county or city level information. A block group is a subdivision of a census tract and is the smallest geographic unit for which the U.S. Census Bureau tabulates data.

RESULTS AND DISCUSSION

Spatial analysis documented colocation in Maryland of WN (as represented by evidence of infected birds, humans, horses, and other vertebrate hosts and infected mosquito pools), presence of *Ae. albopictus* and *Oc. j. japonicus,* and susceptible vertebrate hosts. The dispersal of these 2 species was suggested by the locations of tire collection facilities and tire clean-up sites. Because discarded tires are a common trash item in developed areas, the actual population of source habitats was probably underestimated. We make the assumption in this article that the susceptible vertebrate hosts, particularly birds, are distributed uniformly throughout the state. American crows and other North American corvids appear to be the most susceptible to infection and have been expanding their ranges favored by human activities for several decades (Robbins et al. 1986, Wells and McGowan 1991).

The most prominent indication of virus activity in Maryland is the presence of infected birds. Table 2 and Fig. 1 illustrate the potential for these avian- and mammalian-feeding mosquito species having larval habitats of artificial containers to contact infected birds. Stouffer and Caccamise (1991) showed through radio tracking studies that crows fly 14–18 km per day away from their roost. Johnson (1994) stated that crows commonly fly 10–20 km outward from their roosts each day to feed. Several references on crows indicated that their flight range might be as great as 80 km per day. Even if their flight range was attenuated by the virus infection, significant interactions between birds and mosquitoes occurred within 1.6 km of tire facilities. In Maryland during 2001, 448 birds tested positive for WN, whereas in 2000, 51 birds were reported positive and in 1999, only 1 bird was reported positive. Spatial assessments included 3 and 274 positive birds from the District of Columbia during 2000 and 2001, respectively, and were incorporated in this study.

Our geospatial analysis indicated that infected humans and horses probably did not influence infections of these mosquitoes, probably because these animals are dead-end hosts. The numbers of infected humans and horses were low (Fig. 2). In 2001, 6 human and 5 horse cases of WN were confirmed. Two human cases occurred within 0.8 km of a positive pool of *Culex* spp. mosquitoes, whereas 4 cases occurred within 0.8 km of a tire collection facility. The closest tire clean-up site to a human case was approximately 1.0 km. One horse case was within 8 km of a positive mosquito pool, and another horse case was within 1.3 km of a tire facility.

In 2001, 18 pools of mosquitoes from 12 light traps collected in Maryland were positive for WN. Fourteen of these pools were located in Baltimore City. In addition, there were 40 negative pools in Baltimore City and another 101 in the eastern and central parts of Maryland. Of the positive collections, 15 were composed of *Culex* spp., 2 of *Ae. albopictus,* and 1 of *Aedes vexans* (Meigen). Five licensed tire collection facilities were within 0.8 km of a positive mosquito pool, and 1 of these pools was composed of *Ae. albopictus* in Baltimore City. The 2 positive pools of *Ae. albopictus* were 0.7 km and 1.67 km from licensed tire collection facilities.

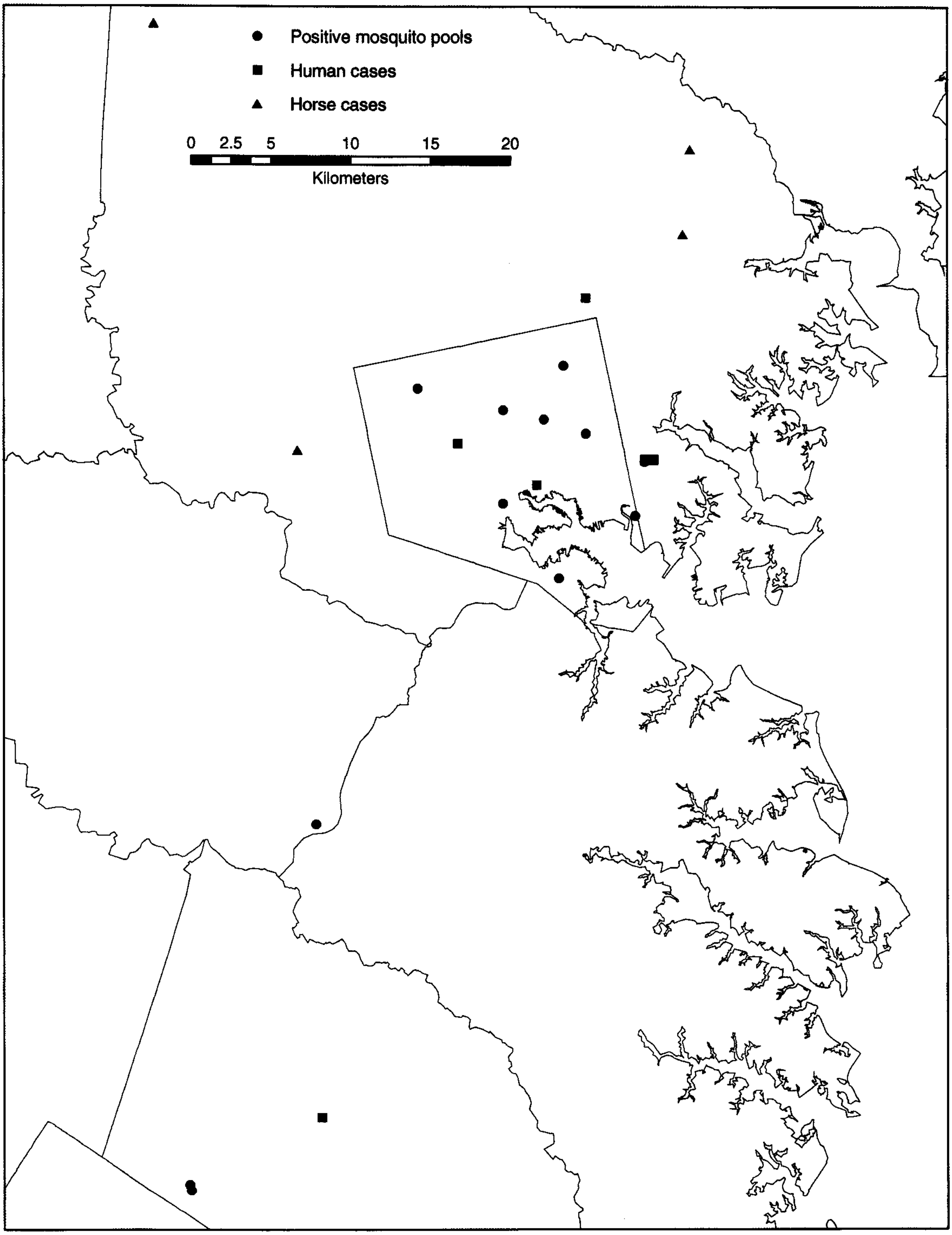

Fig. 2. Map of central Maryland showing locations of humans, horses, and mosquitoes positive for West Nile virus in 2001.

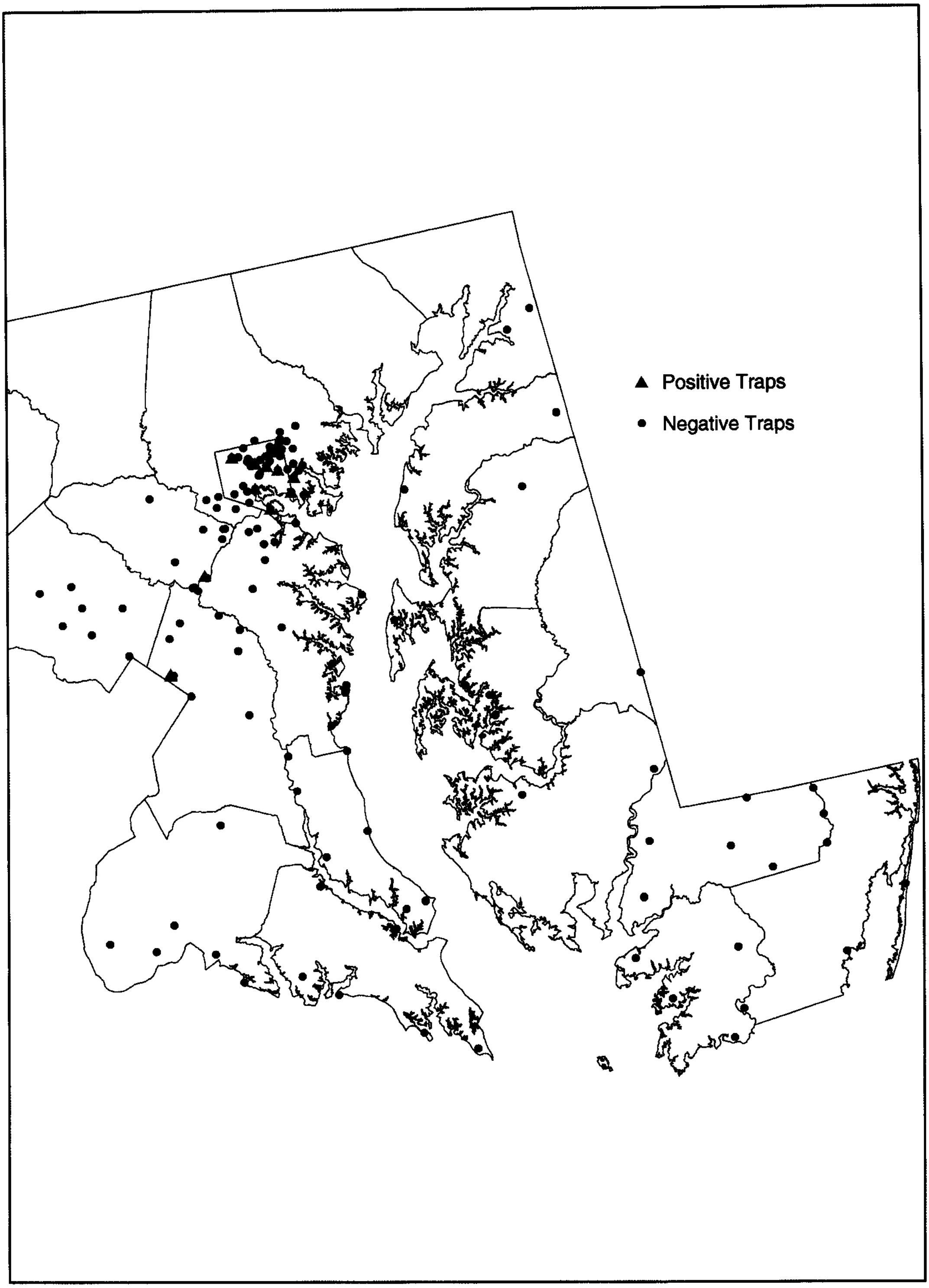

Fig. 3. Map of central and eastern Maryland showing locations of mosquito light/CO_2 traps in 2001 operated by the Maryland Department of Agriculture and the City of Baltimore with West Nile virus-positive and -negative traps indicated.

It is interesting that all of the positive pools of mosquitoes were found in the Baltimore–Washington metropolitan corridor (Fig. 3). This finding suggests that the Baltimore–Washington metropolitan corridor might be an enzootic focus for the virus. It should be noted that this focus for the virus was established quickly because the first dead crow testing positive for the virus was found in 1999 in Baltimore City.

The summary statistics of the developed land-cover class within 1.6 km of infected birds and both positive and negative mosquito pools are presented in Table 3. Land cover within 1.6 km of positive mosquito pools was dominated by development (urban and suburban housing or commercial usages). We found no discernable land-cover pattern around infected bird locations, but these sites were still dominated by development, although to a lesser extent than for the positive mosquito pools. The increased variation in the land cover where infected birds were collected probably indicates their substantial dispersal abilities.

Land cover around the negative mosquito traps varied considerably. As expected, sites within Baltimore City were dominated by development, but other sites outside of the city varied widely, with no single dominant land cover among sites. Some were largely agricultural or developed, whereas others were mostly forest or wetlands. Because the locations of the mosquito light traps were not arrayed according to representative land-cover design, limited statistical associations of trap success with land cover can be made.

The largely urban focus of WN activity suggested that the disease in humans might be associated with various environmental burdens related to environmental justice. According to the United States Environmental Protection Agency (USEPA 1995), the concept of environmental justice denotes that no population of people because of their race, ethnicity, income, national origin, or education should bear a disproportionate share of adverse environmental burdens or hazards. The Institute of Medicine of the National Academy of Sciences (1999) discussed this issue in more detail as it pertains to public health.

The analyses of the environmental justice aspects of the locations of the human cases and the positive mosquito pools (Tables 4 and 5) were equivocal. Data did indicate that both human cases and positive mosquito pools occurred in block groups that would be classified as developed with a minimum of 295 to a maximum of 748 households. Human cases of WN occurred in block groups with lower median income levels than the city or counties in which they were located. Ethnicity presented a different picture. Only the 2 human cases of WN that occurred in Baltimore City were in block groups having a larger percentage of nonwhite households than in the 2 counties where the other cases occurred. The percentage of households receiving so-

Table 4. Selected Census 2000 data for block groups containing human cases of West Nile fever, Maryland.

Location of block group	No. human cases (2001)	Average no. of households in block	Average of 1999 median income per household		Percentage of nonwhite households		Percentage of households receiving social security		Percentage of households receiving public assistance	
			Block group	County or city	Block group	County or city	Block group	County or city	Block group	County or city
Baltimore City	2	584	18,626	30,078	90.01	68.37	25.73	27.67	15.50	7.29
Baltimore County	3	535	39,602	50,667	7.69	25.61	41.95	27.13	1.27	1.72
Prince George's County	1	295	61,845	62,467	46.56	72.96	25.08	16.48	0	1.95

Table 5. Selected Census 2000 data for block groups having positive mosquito pools for West Nile virus, Maryland.[1]

Location of block group	No. positive mosquito pools (2001)	Average no. of households in block group	Average of 1999 median income per household		Percentage of nonwhite households	
			Block group	County or city	Block group	County or city
Baltimore City	14	387	41,548	30,078	18.19	68.37
Baltimore County	1	748	44,038	50,667	4.72	25.61
Prince George's County	2	412	40,078	62,467	74.61	72.96

[1] Census data were not available for 1 location.

cial security in block groups with human cases also showed a variable relationship, with higher percentages in Baltimore and Prince George's counties but a lower percentage in Baltimore City. In addition, the percentage of households receiving some form of public assistance demonstrated an indeterminate conclusion. In Baltimore City, the block groups containing WN cases had about double the public assistance rate of the city as a whole, whereas the cases in the counties were in block groups with lower public assistance percentages.

The Census 2000 data from block groups where positive mosquito pools were detected also presented inconclusive results. Block groups having positive mosquito pools from the counties had lower median income levels than the counties as a whole; but the affected block groups in the city had higher income levels than the city. The examination of the ethnicity of the households in block groups where positive mosquito pools were collected also was inconclusive. The block group in Prince George's County had a slightly higher percentage of nonwhite households, whereas the block groups from Baltimore City and County were substantially lower.

The potential of these 2 mosquito species to serve as bridge vectors of WN was demonstrated by spatial analysis that documented colocation of WN, the potential mosquito vectors, and susceptible vertebrate hosts in Maryland. However, other factors associated with vectorial capacity, such as vector competence, key bionomic characteristics, and environmental and climatic conditions, also must be considered for determining the role of these 2 species of mosquitoes in the epidemiology of WN. Analyses of the environmental justice aspects of block groups with human West Nile fever cases or with positive mosquito pools failed to point to trends of any particular group bearing a disproportionate share of adverse environmental burdens. However, human cases seemed to occur in groups with lower than average income levels.

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