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Comparative Analysis of Distribution and Abundance of West Nile and Eastern Equine Encephalomyelitis Virus Vectors in Suffolk County, New York, Using Human Population Density and Land Use/Cover Data

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ABSTRACT Five years of CDC light trap data from Suffolk County, NY, were analyzed to compare the applicability of human population density (HPD) and land use/cover (LUC) classification systems to describe mosquito abundance and to determine whether certain mosquito species of medical importance tend to be more common in urban (defined by HPD) or residential (defined by LUC) areas. Eleven study sites were categorized as urban or rural using U.S. Census Bureau data and by LUC types using geographic information systems (GISs). Abundance and percent composition of nine mosquito taxa, all known or potential vectors of arboviruses, were analyzed to determine spatial patterns. By HPD definitions, three mosquito species, *Aedes canadensis* (Theobald), *Coquillettidia perturbans* (Walker), and *Culiseta melanura* (Coquillett), differed significantly between habitat types, with higher abundance and percent composition in rural areas. Abundance and percent composition of these three species also increased with freshwater wetland, natural vegetation areas, or a combination when using LUC definitions. Additionally, two species, *Ae. canadensis* and *Cs. melanura*, were negatively affected by increased residential area. One species, *Aedes vexans* (Meigen), had higher percent composition in urban areas. Two medically important taxa, *Culex* spp. and *Aedes triseriatus* (Say), were proportionally more prevalent in residential areas by LUC classification, as was *Aedes trivittatus* (Coquillett). Although HPD classification was readily available and had some predictive value, LUC classification resulted in higher spatial resolution and better ability to develop location specific predictive models.

KEY WORDS mosquito vectors, urban, rural, GIS, West Nile virus

Several important mosquito vector species, including *Culex pipiens* L., are often interchangeably described as urban, periurban, or peridomestic based on their apparent predominance in urban areas worldwide (Gubler and Kuno 1997, Vinogradova 2003, Moncayo et al. 2004, Fonseca et al. 2006). Field-collected data apparently corroborate this notion in the eastern United States despite the scarcity of comprehensive studies comparing urban and rural areas. *Culex quinquefasciatus* (Say) was among the most prevalent larval species found in containers in urban areas in field studies in Florida (Hribar et al. 2001). Of five species studied in Connecticut, only *Cx. pipiens* displayed a significant positive association with increased human population (Andreadis et al. 2004).

The implicit assumption for using the urban versus rural classification is that demographic factors and associated environmental changes can shape mosquito habitat, affecting abundance, distribution, and species composition. Although the distinction between urban and rural areas may seem self-explanatory, the U.S. Census Bureau provides very specific and complex criteria to define urban areas in the United States (U.S. Census Bureau 2002). A simplified 1990 definition of an urbanized area includes a central city and the surrounding densely settled territory that together have a population of 50,000 or more, and a population density exceeding 1,000 people per square mile. The extent of rural areas is determined by exclusion of urbanized areas. The full definition and further modifications of 2000 census data can be found at the Census Bureau website (U.S. Census Bureau 2002).

A different approach using geographic information systems (GISs) has gained increased popularity in recent years as a tool to explore relationships between the environment and arthropod-borne disease vector abundance and distribution (Wood et al. 1992, Beck et al. 1994, Roberts et al. 1995, Cross et al. 1996, Diuk-Wasser et al. 2006). GIS allows quick processing and classification of land use/cover (LUC) data at different spatial levels. Anderson et al. (1976) developed a standard classification system, which has been widely used in the United States, specifically by the U.S.

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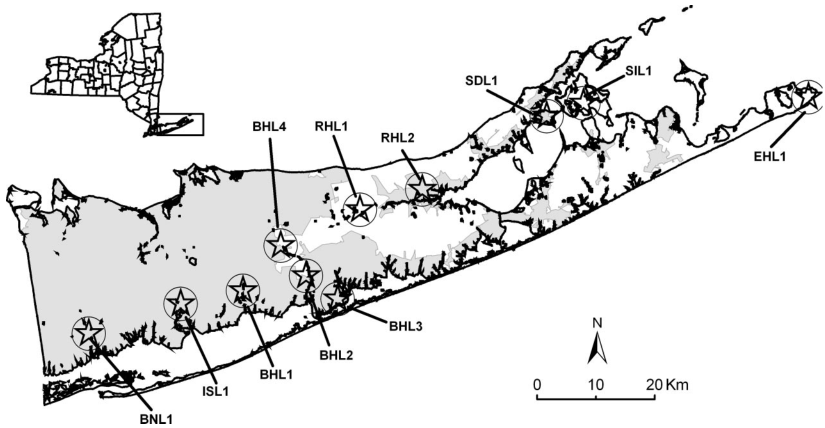

Fig. 1. Suffolk County study sites. Urban areas by 2001 U.S. Census Bureau definition are shown in gray and rural areas are in white.

Geological Survey (USGS 2007). The system uses hierarchical categories to describe LUC in progressively more detail. For example, LUC categories at level I include wetland, developed, and forested areas among others. These classes are further subdivided into level II classes (e.g., deciduous and evergreen forest). Because species distribution and abundance are governed to some degree by abiotic factors such as geology, landscape, rainfall, and temperature, which also define the land cover and determine dominant vegetation together with biotic factors, several studies have investigated the relationship between mosquito bionomics and LUC.

In a Massachusetts study, Moncayo et al. (2000) showed that wetlands accounted for a large proportion of the observed variation in the abundance *Culiseta melanura* (Coquillett), *Aedes vexans* (Meigen), and *Aedes canadensis* (Theobald). Their analysis also revealed a negative correlation between *Ae. vexans* abundance and conifer LUC. Similarly, Diuk-Wasser et al. (2006) found that surface water and distance to wetlands were the among the best predictors for *Ae. vexans*, *Cs. melanura*, and *Culex salinarius* (Coquillett) abundance, whereas *Cx. pipiens* abundance was negatively affected by forest LUC. In Virginia, Barker et al. (2003) clearly demonstrated that two container-breeding mosquito species, *Aedes triseriatus* (Say) and *Aedes albopictus* (Skuse), differed in oviposition preferences discernible using LUC; the former was associated with forested areas, whereas the later was more prevalent in residential areas. The habitat analysis of oviposition preferences across three Florida counties revealed a significant positive association of residential variables and a negative association of vegetation variables with the abundance of *Aedes aegypti* L., whereas *Ae. albopictus* abundance exhibited opposite tendencies. In the same study, *Culex nigripalpus* (Theobald) abundance was positively associated with ponds and open water (Rey et al. 2006).

Suffolk County continues to experience rapid growth and urbanization due to its proximity to metropolitan New York City. Therefore, information concerning potential changes in abundance and composition of vector species is essential for effective surveillance and control efforts. The main objective of the current study was to compare the suitability of these two classification systems, HPD and LUC, for describing patterns of West Nile virus (family *Flaviviridae*, genus *Flavivirus*, WNV)/Eastern equine encephalitis (family *Togaviridae*, genus *Alphavirus*, EEEV) vector abundance and species composition in relation to habitat. The second goal was to determine whether any medically important species exhibited increased abundance in urban (HPD) or residential (LUC) areas.

Materials and Methods

Study Sites and Mosquito Collection. Suffolk County occupies the eastern part of Long Island, NY, ≈15 miles east of New York City, and it has a land area of ≈912 square miles. The county is made up of densely populated suburban areas (typically single-family homes), commercial areas (strip malls and offices), light industrial sites (transportation and services), and rural areas (forested and agricultural). Natural areas, such as wetlands and second growth forest, have been preserved throughout the county. The natural vegetation consists of pine–oak forest (pine barrens) in the southern and eastern parts, with oak–hardwood forest in the northern and central parts of the county (Kurczewski and Boyle 2000). Numerous freshwater wetlands are scattered throughout the area due to an extensive shallow aquifer and soil hydrology.

Eleven study sites were selected in southern (urbanized) and central–eastern (rural) parts of Suffolk County to sample a variety of environments along both urban–rural and west–east gradients (Fig. 1). The locations of the study sites were based on historical and current virus surveillance data, human population density, presence of target species, and logistics. Mosquitoes were collected using one standard CO_2-baited CDC light trap per site weekly from June through September from 2000 to 2004. Specimens were anesthetized using dry ice, brought to the laboratory, and females were identified to species using morphological keys (Means 1979, 1987). *Cx. pipiens* and *Culex restuans* (Theobald) were not separated to species due to the loss of scales during aging or trapping, which renders morphological identification difficult and unreliable (Crabtree et al. 1995, Debrunner-Vossbrinck et al. 1996, Apperson et al. 2002). For this reason, the New York State Department of Health (NYSDOH) arbovirus surveillance program combines *Cx. pipiens* and *Cx. restuans* in pools tested for WNV (Bernard et al. 2001, Lukacik et al. 2006), and we treated these specimens as *Culex pipiens/restuans* here. *Cx. salinarius* is known to occur in Suffolk County (Means 1987), and it may have been collected during the study, but recent analyses indicate that it is present only in low numbers at our study sites. Better identification characters have become available since our study was completed (Andreadis et al. 2005).

Spatial Data. *Human Population Density: Urban versus Rural.* HPD data for Suffolk County were obtained from the U.S. Census Bureau through the Cornell University GIS Repository (2001 TIGER files; CUGIR 2006). The original file contained a map (Urbanized areas, 2000) delineating urban and rural areas by the Census Bureau definition. Each study site was spatially placed on the digital map using ArcMap (ESRI Inc., Redlands, CA) and categorized based on its geographic location inside either an urban or a rural area. To account for potential differences in mosquito abundance and composition at locations in proximity to the interface of urban and rural areas, mixed sites were defined as those located within a 1-km buffer zone around the boundaries between urban and rural polygons. The three resulting categories (urban, mixed, and rural) created a modified HPD classification, which was subjected to the same type of analysis as the original HPD classification (i.e., urban and rural).

LUC Data. LUC data were obtained by digitizing aerial ortho-photographs supplied by Suffolk County (2001) to create an arc 2-km-radius map around each mosquito surveillance site. The 0.5-foot resolution images are publicly available from the NYS GIS clearinghouse (NYS GIS 2002). After initial on-screen digitizing using ArcMap, the geographic location of each study site was buffered and clipped to calculate the proportion of different LUC types for each scale and trap location. The resulting concentric circles of 2-km, 1-km, or 0.2 km (=200-m) radii reflected the appropriate spatial scales of mosquito dispersal. Spatial meso-scales from 1- to 2-km radius are commonly considered relevant to mosquito biology in GIS studies, representing maximum (Kutz et al. 2003, Hakre et al. 2004, Ryan et al. 2004) or average (Moncayo et al. 2000) flight distances. Alternatively, micro-scales of 0.1–0.3-km radius (Rey et al. 2006, Diuk-Wasser et al. 2006) were shown to better fit dispersal patterns of some mosquito species such as *Anopheles* species (Zhou et al. 2004) and container-breeding *Aedes* species (Service 1993, Braks et al. 2003).

The following LUC types were digitized based on visual on-screen examination of the aerial ortho images: residential areas, natural areas, barren land (0.2-km scale only), and saltwater, if present. Residential areas included single-family detached houses with adjacent altered landscape, local roads, and limited commercial areas consisting mostly of strip malls (at the 1- and 2-km scales only). Natural areas consisted of secondary pine–oak forest, oak–pine–maple–hickory forest, wetland areas covered with shrubs and emergent vegetation, and barren land either naturally occurring or artificial, such as vehicle parking lots inside parkland. Barren land constituted a negligible proportion of the total LUC at the 1- and 2-km scales, however, it was assigned into a separate LUC type at the 0.2-km scale because in some cases it occupied up to 12% of the total area (Table 2). Saltwater areas were present at some, but not all sites, and they consisted of open bay or ocean water. These areas were classified as unsuitable mosquito habitat, and they were thus excluded from the LUC analysis.

A map of Suffolk County freshwater wetlands was obtained from the NYS Department of Environmental Conservation through the Cornell University GIS Repository (Freshwater wetlands coverage; CUGIR 2006). Minor corrections were made after visual examination of the 2001 aerial images using ArcMap (ESRI Inc.). Wetland perimeters were established and confirmed by visible changes in vegetation, presence of open freshwater, or both. For the 0.2-km scale, visible signs of water presence were the major indicator of the wetland's extent. The boundaries between different LUC types were generally well defined due to the overwhelmingly suburban character of Suffolk County, where parks and other protected natural areas are surrounded by residential or commercial developments. Each LUC type percentage per total area at the three different scales was determined using ArcMap and used for statistical analysis.

Statistical Analysis. Species abundance and percent composition expressed as relative proportion were the two mosquito population variables used in the analysis. Species abundance was defined as the mean catch of female mosquitoes per trap per night collected at each site during one season. The trap-night catches were $\log_{10}$ (n+1) transformed to normalize the data and to make variance independent of the mean (Bidlingmayer 1969, Reisen and Lothrop 1999). Percent species composition was defined as the relative proportion of female mosquitoes of each species within the total catch collected at each site during one season. All spatial data were processed using ArcGIS 8.2 software (ESRI Inc.). Statistical analysis was carried out using SAS software (SAS Institute, Cary, NC). Statistical significance was defined as $P < 0.01$.

HPD: Urban versus Rural. Analysis of variance (ANOVA), with Bonferroni adjustment, was used to compare mosquito abundance and percent composition between either urban and rural areas (the original HPD classification) or urban, mixed, and rural areas (modified HPD classification). To account for possi-

Table 1. The number of females and relative contribution of mosquito species collected during 2000–04 field seasons

Rank	Species	Total no.	Total %
1	***Aedes canadensis* (Theobald)**	**77,271**	**32.86**
2	***Coquillettidia perturbans* (Walker)**	**49,172**	**20.91**
3	***Culex pipiens/restuans***	**29,995**	**12.76**
4	***Culiseta melanura* (Coquillett)**	**27,153**	**11.55**
5	*Anopheles punctipennis* (Say)	10,306	4.38
6	***Ae. vexans* (Meigen)**	**7,292**	**3.10**
7	*Ae. cantator* (Coquillett)	5,994	2.55
8	*Ae. cinereus* (Meigen)	5,903	2.51
9	*Ae. taeniorhynchus* (Weidemann)	3,616	1.54
10	*Uranotaenia sapphirina* (Osten Sacken)	2,946	1.25
11	*Psorophora ferox* (von Humboldt)	2,525	1.07
12	*Ae. aurifer* (Coquillett)	2,308	0.98
13	***Ae. trivittatus* (Coquillett)**	**2,192**	**0.93**
14	***Ae. sollicitans* (Walker)**	**2,098**	**0.89**
15	*An. quadrimaculatus* (Say)	1,540	0.65
16	*Ae. stimulans* group	1,533	0.65
17	***Ae. triseriatus* (Say)**	**1,191**	**0.51**
18	***Ae. japonicus* (Theobald)**	**852**	**0.36**
19	*Ae. abserratus* (Felt & Young)	630	0.27
20	*Cx. territans* (Walker)	240	0.10
21	*An. crucians* (Weidemann)	182	0.08
22	*Cs. morsitans* (Theobald)	73	0.03
23	*Cs. minnesotae* (Barr)	15	0.01
24	*Ae. excrucians* (Walker)	8	<0.01
25	*Orthopodomyia alba* (Baker)	6	<0.01
26	*Cs. inornata* (Williston)	5	<0.01
27	*An. barberi* (Coquillett)	4	<0.01
28	*Or. signifera* (Coquillett)	2	<0.01
29	*Wyeomyia smithii* (Coquillett)	2	<0.01
30	*Ae. atropalpus* (Coquillett)	1	<0.01

Species in bold are potentially involved in transmission of WNV or EEE in Suffolk County, NY.

ble variability over time, year was included as an independent variable in the model.

LUC Data. Linear regression was used to test for associations between mosquito abundance and percent composition (dependent variables) and the proportion of LUC types (independent variables) at different spatial scales. The relationship was examined separately for each year as well as for the combined 5-yr data to explore temporal variability and to confirm the strength of the overall association.

Results

Mosquito Collection. In total, 235,119 females from 30 species were collected during the 2000–2004 surveillance seasons. Sixty-four specimens could not be positively identified due to damage during collection, and they were removed from the total count, resulting in 235,055 female mosquitoes (Table 1). Only medically important species implicated as potential vectors in WNV and EEEV transmission cycles with at least 100 individual females were subjected to further analysis (nine taxa total, indicated in bold in Table 1).

Ae. canadensis was the predominant species representing about one third (32.9%) of the total, followed by *Coquillettidia perturbans* (Walker) (20.9%), *Culex pipiens/restuans* (12.8%), and *Cs. melanura* (11.5%). The remaining species contributed <5% each (Table 1).

HPD: Urban versus Rural. The spatial alignment resulted in five rural and six urban trap sites classified according to their precise geographic locations within either urban or rural polygons using U.S. Census Bureau data (Table 2). The standard HPD definition was further modified to account for those trap sites located in proximity to the urban–rural interface. Sites located within 1-km distance from the urban–rural boundary were defined as mixed resulting in four urban, four mixed, and three rural sites (Table 2). Sites thus classified were compared in terms of abundance and percent composition of the nine mosquito taxa by ANOVA with Bonferroni adjustment. The model included main effects for year and HPD type, two interaction terms for species with year or HPD type to consider temporal and spatial changes separately for each species, and a term accounting for the nested design (sites within HPD type).

For mosquito abundance, the main effect of year was significant ($F = 6.0$; df = 4, 432; $P < 0.001$), whereas that of HPD type was not ($F = 0.3$; df = 1, 9; $P = 0.6$). Both interaction terms were significant, taxon by year ($F = 1.9$; df = 32, 432; $P = 0.003$) and taxon by HPD type ($F = 7.3$; df = 8, 432; $P < 0.001$). Similar results were obtained with the modified HPD

Table 2. Study sites: HPD classification and percentage (%) of major LUC types at three different spatial scales

Site name	Residential %			Wetland %			Natural areas %			Bar %
	0.2 km	1.0 km	2.0 km	0.2 km	1.0 km	2.0 km	0.2 km	1.0 km	2.0 km	0.2 km
BHL1 (U)	43.2	74.0	72.3	3.0	12.4	7.4	56.8	26.0	27.7	0.0
BHL2 (R)[m]	10.4	15.2	22.6	14.3	11.2	8.2	89.6	84.8	77.4	0.0
BHL3 (U)	31.7	41.6	52.8	4.5	10.5	7.6	68.3	58.4	47.2	0.0
BHL4 (R)[m]	0.0	14.3	20.4	7.6	14.8	6.4	100.0	85.7	79.6	0.0
BNL1 (U)	24.1	64.6	77.8	0.0	22.2	9.7	75.9	35.4	22.2	0.0
EHL1 (R)	12.9	4.2	2.4	0.8	23.8	26.4	75.1	95.8	97.6	12.0
ISL1 (U)	0.0	0.0	6.4	19.7	37.2	18.6	100.0	100.0	93.6	0.0
RHL1 (R)	0.0	0.4	2.7	25.9	28.6	14.6	91.1	99.6	97.3	8.9
RHL2 (U)[m]	0.0	37.6	45.7	28.0	14.5	6.9	97.3	62.4	54.3	2.7
SDL1 (U)[m]	38.5	31.1	35.0	10.3	3.8	11.9	59.9	68.9	65.0	1.6
SIL1 (R)	9.2	30.1	28.7	20.9	13.7	11.7	90.8	69.9	71.3	0.0
Min	0.0	0.0	2.4	0.0	3.8	6.4	56.8	26.0	22.2	0.0
Max	43.2	74.0	77.8	28.0	37.2	26.4	100.0	100.0	97.6	12.0

Barren LUC type, Bar, was delineated at 200-m scale only. Natural areas LUC type included mostly forested and wetland areas. U indicates an urban site, whereas R indicates a rural site. Mixed (urban and rural sites in proximity) are shown with superscript letter m.

Table 3. Comparison of mosquito species abundance in urban versus rural areas (HPD classification) by ANOVA of $\log_{10}$-transformed trap night means (df = 2, 424 for all comparisons)

Species/HPD type	Urban	Rural	*F*	*P*
Ae. canadensis	**4.52**	**9.61**	**10.81**	**0.001**
Ae. japonicus	0.52	0.27	0.83	0.364
Cs. melanura	**4.24**	**10.95**	**17.16**	**<0.001**
Cq. perturbans	**1.66**	**6.13**	**24.64**	**<0.001**
Cx. pipiens/restuans	12.28	12.45	0.00	0.948
Ae. sollicitans	0.57	0.09	3.47	0.063
Ae. triseriatus	0.72	0.54	0.30	0.586
Ae. trivittatus	0.84	0.48	1.18	0.278
Ae. vexans	2.69	1.48	4.05	0.045

Williams or logarithmic means (shown) were calculated according to the published procedure (Downing 1976). Bold text indicates statistically significant results at $P < 0.01$.

classification (i.e., urban, mixed, and rural; data not shown). Three species, *Ae. canadensis, Cq. perturbans,* and *Cs. melanura,* had significantly higher abundance in rural areas compared with urban areas (Table 3), whereas the mixed areas produced intermediate levels of abundance for these three species (data not shown).

For percent species composition, the main effects of year ($F = 0.3$; df = 4, 432; $P = 0.869$) and HPD type ($F = 0.04$; df = 1, 9; $P = 0.843$) were not significant. The species by year interaction term was not significant ($F = 1.5$; df = 32, 432; $P = 0.053$), whereas the species by HPD type term was significant ($F = 6.9$; df = 8, 432; $P < 0.001$). Similar results were obtained with the modified HPD classification (i.e., urban, mixed, and rural; data not shown). As with species abundance, collections contained a significantly greater percentage composition of *Cq. perturbans* and *Cs. melanura* in rural areas compared with urban areas (Table 4), whereas mixed areas produced intermediate levels of abundance and percent composition for these two species (data not shown). Percent composition of *Ae. canadensis* was marginally greater in rural areas ($P = 0.026$). The modified HPD classification resulted in significant differences in the species percent composition between urban (lowest) and rural (highest) categories, with the mixed category in the middle ($F = 5.4$; df = 2, 424; $P = 0.005$). *Ae. vexans* had a higher percent composition in urban areas (Table 4), but there were no significant differences among the three categories in the modified HPD classification. No statistically significant differences in abundance or percent composition were found for the remaining species using either the standard or modified HPD classifications.

Table 4. Comparison of mosquito species percent composition in urban versus rural areas (HPD classification) by ANOVA of $\log_{10}$-transformed trap night means (df = 2, 424 for all comparisons)

Species/HPD type	Urban	Rural	*F*	*P*
Ae. canadensis	4.48	7.59	5.01	0.026
Ae. japonicus	0.60	0.43	0.31	0.579
Cs. melanura	**5.36**	**11.91**	**12.41**	**<0.001**
Cq. perturbans	**1.54**	**4.68**	**16.00**	**<0.001**
Cx. pipiens/restuans	20.06	13.62	3.29	0.070
Ae. sollicitans	0.74	0.09	5.27	0.022
Ae. triseriatus	0.88	0.55	0.93	0.334
Ae. trivittatus	0.84	0.34	2.49	0.115
Ae. vexans	**3.39**	**1.35**	**9.65**	**0.002**

Williams or logarithmic means (shown) were calculated according to the published procedure (Downing 1976). Bold text indicates statistically significant results at $P < 0.01$.

Land Use/Cover. The proportion of major LUC types varied considerably among the sites at the three scales (Table 2). Per total area, the residential areas covered 0–77.8%, wetlands 0–37.2%, natural areas (combined forest and wetland) 22.2–100%, and barren land (at the 0.2-km scale only) 0–12.0%. There was an inverse relationship between residential and natural areas at 1- and 2-km scales, because natural areas included both forested areas and wetlands. At the 0.2-km scale this relationship was much weaker at some sites due to the presence of barren land.

Scatter plots and statistically significant regression lines were examined visually for possible artifacts. Cases with a significant overall relationship combined with nonsignificant relationships by year (Tables 5 and 6) suggested artifacts due to outliers (data not shown), and were regarded as not significant. There seemed to be a positive correlation among the number of years within which the relationship was significant, and the strength of the overall association (R^2 value).

Abundances of three mosquito species (*Ae. canadensis, Cq. perturbans,* and *Cs. melanura*) increased with wetland LUC at either 0.2- or 1-km scales (Table 5). LUC accounted for ≈40 to 53% of the observed variance, depending on the species. Abundances of two species (*Ae. canadensis* and *Cs. melanura*) were also positively correlated with natural areas accounting for 25 to 54% of the observed variance, and negatively correlated with residential areas, accounting for 27 to 60% of the observed variance depending on the scale.

Percent compositions of these same three species exhibited similar trends, being highest at wetland LUC (Table 6). Percent compositions of three additional species, *Ae. triseriatus, Aedes trivittatus* (Coquillett), and *Cx. pipiens/restuans*, increased with residential area (explaining from 18% to 41% of the variance), and, correspondingly, were negatively affected by natural areas. Percent composition of *Cx. pipiens/restuans* also exhibited a negative relationship with wetlands (from 21% to 46% of the observed variance depending on the spatial scale). No significant associations were identified for the remaining species.

Discussion

Our results show that both HPD and LUC classification systems can be used to distinguish mosquito distribution patterns when applied to trap catch results from Suffolk County, NY. Analysis using HPD classification showed that *Cs. melanura* and *Cq. perturbans* (species potentially involved in EEEV transmission) made up a greater proportion of the trap catch in rural than in urban areas (Tables 3 and 4),

Table 5. Linear regression analysis of mosquito species abundance as a function of LUC types at three spatial scales

Species	Parameter	Res0.2km	Res1km	Res2km	Wet0.2km	Wet1km	Wet2km	Nat0.2km	Nat1km	Nat2km
Ae. canadensis	Beta	−0.030	−0.014	−0.012	0.039	0.042	0.017	0.029	0.014	0.012
	R^2	**0.601**	**0.329**	**0.268**	**0.402**	**0.401**	0.028	**0.537**	**0.329**	**0.268**
	p	<0.01	<0.01	<0.01	<0.01	<0.01	0.22	<0.01	<0.01	<0.01
	No. years	**5**	**3**	**2**	**3**	**3**		**5**	**3**	**2**
Cs. melanura	Beta	−0.020	−0.014	−0.014	0.040	0.022	0.020	0.018	0.014	0.014
	R^2	**0.336**	**0.386**	**0.423**	**0.529**	0.143	0.046	**0.254**	**0.386**	**0.423**
	p	<0.01	<0.01	<0.01	<0.01	<0.01	0.12	<0.01	<0.01	<0.01
	No. years	**4**	**4**	**4**	**5**	0		**4**	**4**	**4**
Cq. perturbans	Beta	−0.015	−0.009	−0.008	0.041	−0.004	−0.012	0.013	0.009	0.008
	R^2	0.180	0.132	0.134	**0.493**	0.005	0.016	0.123	0.132	0.134
	p	<0.01	0.01	0.01	<0.01	0.62	0.35	0.01	0.01	0.01
	No. years	0	0	0	**5**			0	0	0
Cx. pipiens/restuans	Beta	0.003	−0.001	−0.001	−0.006	−0.005	0.000	−0.005	0.001	0.001
	R^2	0.016	0.003	0.001	0.025	0.014	0.000	0.036	0.003	0.001
	p	0.36	0.68	0.81	0.25	0.39	1.00	0.17	0.68	0.81
	No. years									
Ae. vexans	Beta	0.000	0.001	0.001	0.002	0.005	0.007	0.000	−0.001	−0.001
	R^2	0.001	0.008	0.022	0.008	0.035	0.029	0.000	0.008	0.022
	p	0.86	0.50	0.28	0.51	0.17	0.21	0.90	0.50	0.28
	No. years									

Beta coefficient (the slope) of the regression equation (Beta); R^2, overall statistical significance (p, bold if significant at <0.01 unless no. years = 0); and the number of years with statistically significant regression at $P < 0.05$ when tested separately (no. years) are indicated. Res, residential areas; Wet, wetland areas; Nat, natural areas. Only statistically significant results or data for common species are shown.

possibly due to reduced larval habitat and sensitivity to eutrophication. Similar results were also obtained for the abundance of *Ae. canadensis,* a potential epizootic EEEV vector in New York State (Howard et al. 1988) and a competent WNV vector under laboratory conditions (Turell et al. 2005), with the virus occasionally isolated from field-collected specimens in this area (Andreadis et al. 2004). Another potential EEEV and WNV bridge vector, *Ae. vexans* (Turell et al. 2005), contributed a higher proportion to the trap catch in urban areas where numerous water recharge basins, greenbelts, and other areas holding temporary pools provide ample floodwater larval habitat for this species. Interestingly, abundance and percent com-

Table 6. Linear regression analysis of mosquito species percentage of composition as a function of LUC types at three spatial scales

Species	Parameter	Res0.2km	Res1km	Res2km	Wet0.2km	Wet1km	Wet2km	Nat0.2km	Nat1km	Nat2km
Ae. canadensis	Beta	−0.023	−0.010	−0.009	0.023	0.034	0.015	0.023	0.010	0.009
	R^2	**0.627**	**0.292**	**0.238**	**0.249**	**0.477**	0.040	**0.619**	**0.292**	**0.238**
	p	<0.01	<0.01	<0.01	<0.01	<0.01	0.14	<0.01	<0.01	<0.01
	No. years	**5**	**3**	**2**	**1**	**4**		**5**	**3**	**2**
Cs. melanura	Beta	−0.011	−0.009	−0.010	0.027	0.007	0.013	0.010	0.009	0.010
	R^2	0.135	**0.213**	**0.301**	**0.320**	0.019	0.030	0.116	**0.213**	**0.301**
	P	0.01	<0.01	<0.01	<0.01	0.32	0.21	0.011	0.00	<0.01
	No. years	0	**1**	**2**	**2**			0	**1**	**2**
Cq. perturbans	Beta	−0.009	−0.005	−0.005	0.029	−0.013	−0.014	0.008	0.005	0.005
	R^2	0.100	0.080	0.093	**0.406**	0.070	0.036	0.078	0.080	0.093
	p	0.02	0.04	0.02	<0.01	0.05	0.17	0.04	0.04	0.02
	No. years				**4**					
Cx. pipiens/restuans	Beta	0.016	0.007	0.007	−0.028	−0.020	−0.010	−0.017	−0.007	−0.007
	R^2	**0.406**	**0.197**	**0.178**	**0.465**	**0.209**	0.021	**0.397**	**0.197**	**0.178**
	p	<0.01	<0.01	<0.01	<0.01	<0.01	0.29	<0.01	<0.01	<0.01
	No. years	**5**	**1**	**1**	**5**	**2**		**5**	**1**	**1**
Ae. triseriatus	Beta	0.001	0.004	0.004	−0.006	0.002	−0.003	0.000	−0.004	−0.004
	R^2	0.002	**0.176**	**0.194**	0.080	0.008	0.008	0.001	**0.176**	**0.194**
	p	0.75	<0.01	<0.01	0.04	0.52	0.51	0.81	<0.01	<0.01
	No. years		**3**	**3**					**3**	**3**
Ae. trivittatus	Beta	0.001	0.003	0.003	−0.003	0.003	−0.002	0.000	−0.003	−0.003
	R^2	0.006	**0.202**	**0.245**	0.037	0.029	0.006	0.001	**0.202**	**0.245**
	p	0.59	<0.01	<0.01	0.16	0.22	0.56	0.79	<0.01	<0.01
	No. years		**2**	**1**					**2**	**1**
Ae. vexans	Beta	0.006	0.005	0.005	−0.009	−0.001	0.005	−0.006	−0.005	−0.005
	R^2	0.131	0.180	0.204	0.118	0.001	0.012	0.118	0.180	0.204
	p	0.01	<0.01	<0.01	0.01	0.78	0.42	0.01	<0.01	
	No. years	0	0	0	0			0	0	0

Beta coefficient (the slope) of the regression equation (Beta); R^2, overall statistical significance (p, bold if significant at <0.01 unless no. years = 0), and the number of years with statistically significant regression at $P < 0.05$ when tested separately (no. years) are indicated. Res, residential areas; Wet, wetland areas; Nat, natural areas. Only statistically significant results or data for common species are shown.

position of *Cx. pipiens/restuans*, the most important vectors of WNV, were similar in urban and rural areas confirming the ability of these species to use different types of larval habitat. Andreadis et al. (2004) found *Cx. pipiens* abundance positively correlated with urban areas and no significant associations between HPD and abundance for four additional species (*Cx. restuans*, *Cs. melanura*, *Cx. salinarius*, and *Ae. vexans*) in Connecticut. In that study, mosquito abundance was correlated with human population per unit area, rather than using an urban–rural classification scheme, which might account for the different results.

Several investigators have used LUC classification to account for variability in mosquito abundance and distribution. Using this approach, three species with higher abundance in rural areas, *Ae. canadensis*, *Cq. perturbans*, and *Cs. melanura*, displayed positive association between abundance and increased wetland areas in our study. This result fits with what is known of the natural histories of these species because they are common in freshwater wetlands (Means 1979, 1987). Similar studies in the northeastern United States found positive associations between wetlands and abundance of *Ae. canadensis* (Moncayo et al. 2000) and *Cs. melanura* (Moncayo et al. 2000, Diuk-Wasser et al. 2006). Contrary to our results, others found wetland LUC accounted for some of the observed variation in *Ae. vexans* abundance (Moncayo et al. 2000, Diuk-Wasser et al. 2006), whereas no such relationship was reported for *Cq. perturbans* (Moncayo et al. 2000). These discrepancies might underscore the differences in soil type and habitat between the study locations in Suffolk County and southeastern New England, which differ in hydrology, vegetation composition, and level of anthropogenic disturbance. *Culex pipiens/restuans* became more predominant with increased residential areas reflecting reduced abundance of other dominant mosquito species (*Ae. canadensis*, *Cq. perturbans*, and *Cs. melanura*) negatively affected by anthropogenic factors, whereas *Culex* species abundance remained stable.

Kilpatrick et al. (2005) suggested that percent composition of an important vector species could contribute to the overall risk of human infection with WNV. The proposed model was used to estimate the relative risk of WNV transmission by major vector species in New York (Kilpatrick et al. 2005) and North Dakota (Bell et al. 2005). Accordingly, increased risk of human exposure to mosquito-borne viruses is also expected to be associated with species proportionally more prevalent in residential (LUC) or urban (HPD) areas. Four such species were identified by this study (*Cx. pipiens/restuans*, *Ae. triseriatus*, *Ae. trivittatus*, and *Ae. vexans*). Percent composition of the WNV vectors *Culex pipiens/restuans* (Bernard and Kramer 2001, Bernard et al. 2001, White et al. 2001) increased with residential areas up to about one half of the total mosquito population in some heavily residential sites. Percent composition of *Ae. triseriatus*, a species known to harbor WNV in this area (Bernard et al. 2001, Andreadis et al. 2004) and a competent WNV vector in the laboratory (Turell et al. 2005), increased almost four-fold between the sites with the smallest and the largest proportion of residential LUC type (data not shown). Similarly, WNV was isolated from field collected *Ae. trivittatus* in New York and Connecticut (Andreadis et al. 2004, Lukacik et al. 2006); this species also was shown a competent bridge vector in the laboratory (Tiawsirisup et al. 2004). *Ae. vexans* is considered one of the most likely bridge WNV vectors due to repeated WNV isolations from field-collected pools (Andreadis et al. 2004, Lukacik et al. 2006), high vector competence in the laboratory (Turell et al. 2005), and high population abundance (Kilpatrick et al. 2005). These results have important practical implications for mosquito management. One of the central goals of mosquito surveillance and management within residential areas of Suffolk County should be detection, reduction, and treatment of potential larval habitat for *Culex* species (recharge and catch basins, artificial containers), *Ae. triseriatus* (artificial containers and tree holes), and *Ae. trivittatus* (recharge basins). In the urbanized parts of the county, larval habitats of floodwater *Ae. vexans* may not be limited to groundwater recharge basins in residential areas but also include the surrounding natural and mixed use area because the urban/rural classification does not differentiate these habitats.

Greater numbers of the predominant inland mosquitoes, *Ae. canadensis* and *Cq. perturbans*, as well as *Cs. melanura*, the main enzootic vector of EEEV in Suffolk County (Ninivaggi and Guirgis 1994, Howard et al. 1995), are found in rural areas, and they also are associated with wetlands, natural areas, or both. *Cs. melanura* has more restricted requirements preferring red maple swamps and woodland bogs for breeding (Means 1987). Our results, similar to those of Moncayo et al. (2000) and Diuk-Wasser et al. (2006), suggest that a large fraction of wetlands within the less developed portions of the study area might be used by this species. Together with increased populations of potential EEEV bridge vectors, especially *Cq. perturbans* (Howard et al. 1988, 1994, 1995; Ninivaggi and Guirgis 1994) within the same areas, this pattern might produce favorable conditions for EEEV transmission to humans. Interestingly, *Aedes sollicitans* (Walker), another potentially important EEEV bridge vector in this region (Crans 1977, 1986; Andreadis et al. 1998) was present, but it did not exhibit any discernible spatial pattern apart from having much higher numbers caught in traps located near its salt marsh habitat (data not shown).

In summary, the comparative analysis of HPD (urban versus rural) and LUC type classification systems as applied to mosquito abundance and species composition in Suffolk County, NY, demonstrated their prospective pros and cons. The traditional HPD classification was readily available and had predictive value for some mosquito species; however, it was unusable for further modeling and hypothesis testing mainly due to its categorical nature. The LUC classification using GIS required more effort, but it provided significant results for more species and the finer discrimination of sites in terms of habitat type on the landscape scale directly relevant to the mosquito ecology. Therefore, we conclude that the LUC classification system provided better spatial resolution than did HPD, and we found it more useful in describing mosquito distribution patterns. To achieve its full potential, the LUC system needs further refinement to characterize ecological requirements of medically important mosquito species, to analyze mosquito abundance as a function of land cover changes, and to become an integral part of a comprehensive vector surveillance and control program.

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