Research Article

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Area-wide management of *Aedes albopictus*: choice of study sites based on geospatial characteristics, socioeconomic factors and mosquito populations[†]

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Abstract

BACKGROUND: *Aedes* (*Stegomyia*) *albopictus* (Skuse), the Asian tiger mosquito, is an introduced invasive species in the United States that is responsible for a significant proportion of service requests to local mosquito control programs. This container-utilizing mosquito is refractory to standard mosquito abatement measures in the United States. This study is part of a USDA-ARS project to develop an area-wide management strategy for *Ae. albopictus*. The goal was to identify three study sites, similar in socioeconomic parameters, geography and *Ae. albopictus* abundance, in urban and suburban areas in Mercer and Monmouth counties in New Jersey. Prior service requests and light trap counts and also detailed county maps were used to chose nine preliminary sites (four in Mercer and five in Monmouth) where weekly surveillance for *Ae. albopictus* was performed throughout the 2008 active season.

RESULTS: Although outliers were detected, socioeconomic variables in the study sites within each county were fairly consistent. *Ae. albopictus* abundance was associated with poverty levels and had the highest maxima in Mercer, although average mosquito abundance was similar in urban Mercer and suburban Monmouth.

CONCLUSION: Three study sites in each county were identified for future studies. The summer-long surveillance also revealed socioeconomic variables critical for the development of integrated mosquito management.

Keywords: nuisance mosquito; control; New Jersey; GIS; BGS traps; area-wide

1 INTRODUCTION

Aedes (*Stegomyia) albopictus* (Skuse) (Diptera: Culicidae), the Asian tiger mosquito, is indigenous to both tropical and temperate regions of East Asia, but over the last few decades it has expanded its range across several continents.[1] Its aggressive anthropophilic host preference and daytime biting behavior make this species a major pest where it has become established.[2] As a container-utilizing species with desiccation-resistant eggs capable of winter dormancy, *Ae. albopictus* has been transported globally within artificial containers, particularly in used tires[3] and in shipments of ornamental plants.[4] Although some adult *Ae. albopictus* had been found previously in the continental United States,[5] in 1985 established populations were detected in Houston, Texas.[6] Since then, the species has spread throughout the southeastern and eastern United States.[1,3,7] *Ae. albopictus* was first detected in New Jersey in 1995, from a trap collection in Keyport, Monmouth County,[8] and now occurs throughout most of the state.[9]

Ae. albopictus is susceptible and able to transmit at least 26 arboviruses.[10] Although, during the last two decades, continental US populations of *Ae. albopictus* have been found to be infected with several important arboviruses, including Cache Valley, eastern equine encephalitis, Jamestown Canyon, La Crosse and West Nile,[7,11,12] its role as a major disease vector in the continental United States has not been fully realized.[10] However, the outbreak

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of dengue fever in Hawaii during 2001–2002[13] and of chikungunya virus in Italy during 2007,[14] as well as the multiple isolated cases of chikungunya and dengue viruses in France in 2010 (ProMED Alert, 18 and 26 September 2010), underscores the vector potential of this invasive species in its introduced range.

Although many suburban and urban areas in the United States have large *Ae. albopictus* populations, no large-scale studies have been conducted to investigate effective control strategies to be adopted by health agencies and mosquito control programs.[7,15] During a routine service request inspection process, standing water is checked by inspectors, and larvicides are applied if needed. Yard sanitation and education of the resident are also part of the service request routine (Farajollahi A and Healy S, personal experience). In some instances, inspectors may respond to high adult populations of *Ae. albopictus* with localized adulticiding (Farajollahi A, personal experience). In the United States and abroad, these control measures have been mostly unsuccessful unless aggressive measures were taken in the early stages of the infestation[16] (Strickman D, unpublished). For example, in Grand Cayman Island, where the species arrived in 1997, an extensive integrated pest management project was developed between 1997 and 2001 to prevent establishment. In spite of these efforts, *Ae. albopictus* currently occurs in large numbers across the island.[17]

Although *Ae. albopictus* can be found in manicured gardens in upper-scale developments, where a bird bath or children's toys may generate large populations,[18] the population density of this species is more often associated with the amount of discarded containers in the habitat and with low socioeconomic levels.[19] For example, slums (poverty-level socioeconomic housing developments) in Singapore produce very high *Ae. albopictus* populations, leading the government to eliminate these habitats systematically in an attempt to control the species.[20] However, this effort failed because large populations of *Ae. albopictus* were also associated with residences in higher-income areas,[21] which were capable of continuously providing individuals to recolonize the areas from which the species had been eliminated. This example highlights the importance of employing an area-wide approach to controlling *Ae. albopictus* and possibly most mosquitoes. Control has to be made at the community level, as a single non-complying household can infest an entire neighborhood.

Programs aimed at controlling or eradicating *Ae. albopictus* have suffered from the lack of an efficient trap for this species, which has prevented the accurate assessment of control. Like most daytime-biting species, *Ae. albopictus* is not attracted strongly to standard surveillance equipment such as light traps.[22,23] The BG Sentinel™ trap (Biogents AG, Regensburg, Germany) uses contrasting black and white colors and a human scent lure to attract mostly daytime-biting, container-breeding *Aedes*. The effectiveness of this trap has been demonstrated for temperate populations of *Ae. albopictus*.[22,23]

The goal of the overall project is to develop strategies for effective area-wide control of *Ae. albopictus*. The approach is semi-experimental and will assess the impact of different control strategies in large areas with similar infestations of *Ae. albopictus* as well as similar geography and socioeconomic status. The motivation for locating this area-wide project in New Jersey was driven by the presence of a good mosquito abatement infrastructure and the relatively recent introduction of the species leading to a community memory of low populations of daytime-biting mosquitoes. New Jersey is at the northernmost range of the *Ae. albopictus* distribution on the eastern coast of the United States; therefore, population abundance is markedly cyclical according to the season. This seasonal variation facilitates the identification of critical life-history parameters because perturbations in the seasonal pattern are sensitive indicators of any negative effect on the population.

In this first phase of the project, the objective was to choose three 1000-parcel study sites with similar socioeconomic parameters, geography and *Ae. albopictus* abundance for use in subsequent comparative studies of the efficacy of various control approaches. In future phases of this project, different control strategies will be deployed in two of the three sites, with the third acting as an untreated control. Efforts are being duplicated in inner-city Trenton in Mercer County and in coastal suburban townships of Monmouth County (Fig. 1) in order to compare the effect of geography, education levels and socioeconomics on the overall development of an effective and sustainable control program.

2 MATERIALS AND METHODS

2.1 Mapping and geospatial processing

Shapefiles (e.g. Figures 2 and 3) for parcels and street centerlines were projected using Universal Transverse Mercator coordinates and the North American Datum 1983 coordinate system (NAD 83[24]). Maps of the sites were selected, clipped and merged using Environmental Systems Research Institute (ESRI™, Redlands, CA) geospatial processing tools based on the street centerlines, and were evaluated using ArcMap™ symbology classification statistics.

2.2 Initial site selection

Each site is a group of approximately 1000 parcels, each parcel corresponding to a structure or a house (residential or commercial) and surrounding yard. The parcels in a potential study area were distributed roughly in a square. Initial selection of broad areas was based primarily on the concentration of past *Ae. albopictus*-related mosquito service requests and the abundance of *Ae. albopictus* in traps from routine disease and nuisance surveillance monitoring[9] (Healy SP, unpublished). Next, groups of 1000 parcels of similar size were chosen within common elementary school zones, and driving times between these potential sites were assessed during short visits in the spring of 2008. Study sites in each county were at least 0.5 km apart (from edge to closest edge), except for Keansburg and Middletown, which were adjacent to each other. The preferred minimum distance between sites was based on the flight range of *Ae. albopictus*, considered to be approximately 400 m.[25,26] The proximity and range of local elementary schools were taken into consideration because education programs are important components of integrated mosquito management and will be part of the operational strategy in future years.

The analyses made it possible to narrow selected choices to four sites of 1000 parcels in Mercer County and five sites in Monmouth County, where a weekly surveillance for *Ae. albopictus* using BGS traps was conducted during the summer and fall of 2008. The socioeconomic levels of the sites were also compared using information obtained from county parcel data from the 2000 US Census (http://www.census.gov), such as high school and college graduation rates, population living below the poverty level and median household income.

2.3 Study sites surveyed

Mercer County is located northeast of Philadelphia, Pennsylvania, and has a population of 370 000, including the state capital, Trenton. Monmouth County is located south of New York City and has a population of 650 000 (Fig. 1A). In Mercer County, three sites

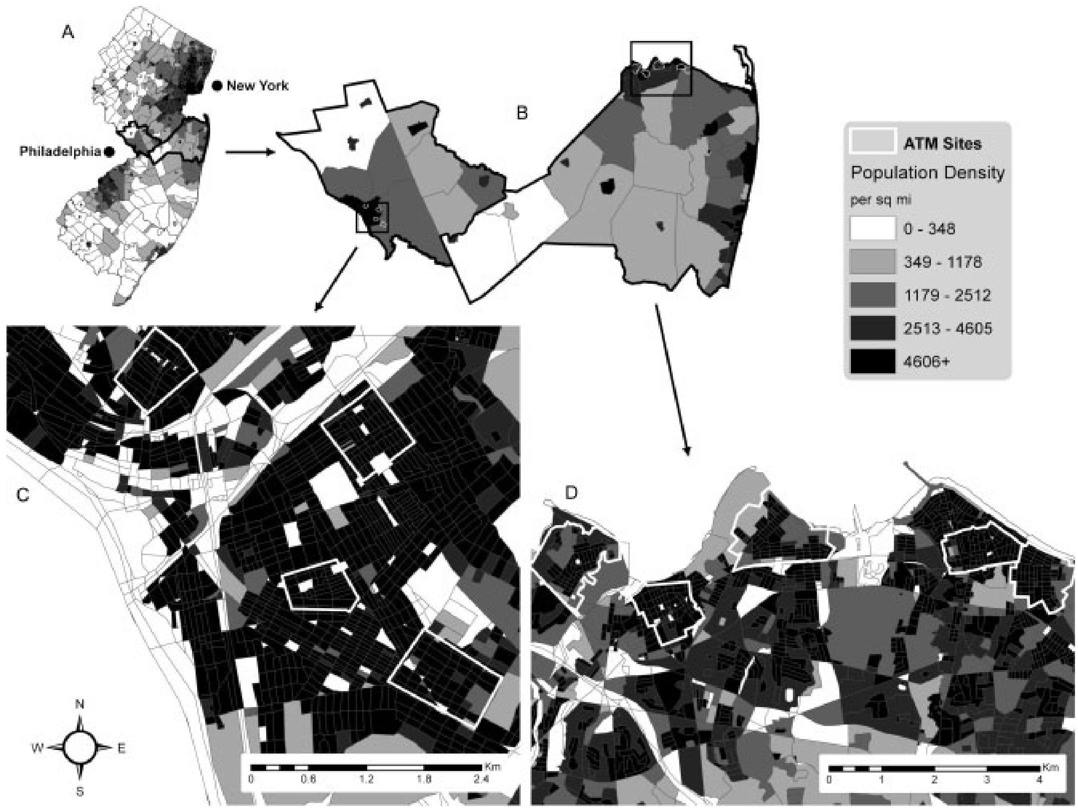

Figure 1. Maps of study sites in Mercer and Monmouth counties, New Jersey, shown with population density in the background. (A) Mercer and Monmouth counties. (B) The study areas in Mercer and Monmouth counties. (C) A map showing the locations of the four Mercer County study sites (plus county parcels) in 2008. (D) A map showing the locations of the five Monmouth County study sites (plus county parcels) in 2008.

(Brunswick, South Olden and Cummings) were located in the City of Trenton, and one site (South Clinton) was located south of the city in Hamilton Township (Figs 1B and 1C). In Monmouth County, the study sites were located in the Raritan Bayshore region (Fig. 1B) in the municipalities of Aberdeen (Cliffwood Beach), Keyport, Union Beach, Keansburg and Middletown, from east to west respectively (Fig. 1D). The size of the study sites in each county reflected the average size of each parcel, which is the smallest unit within each site and represents individual homes, businesses or other buildings such as churches and other communal spaces, and surrounding yards.

2.4 Surveillance protocol

ArcGIS was used to divide each study site into a grid of groups of parcels or 'cells' using existing boundaries such as roads and alleys or the shoreline. Cells were the sampling units. Sampling was performed with BGS traps deployed continuously for 24 h and placed in each of the cells selected. The specific location of the trap within the cell was based on accessibility, homeowner permission and safety considerations. The need to have alternative parcels for trap locations was one of the factors influencing the choice of the size of a 'cell' within each site. Parcels in Mercer County, especially in heavily urban Trenton, were smaller (200 m^2) than in suburban Monmouth County, so that site size was larger (450 m^2) on average in Monmouth County. This difference also influenced the size of the grids used during surveillance and the number of traps deployed.

Maps displaying the cells were created, with an address for each parcel and features such as roads, schools and parks. These maps served as visual limits for the trapping location and as guides to be used by the field teams. Each cell was assigned a unique identification number, and each week a random number generator (MS Office Excel™ 2007; Microsoft Corp., Redmond, WA) was used to select specific cells for sampling. Cells were randomly selected with replacement (i.e. they could be resampled); therefore, each weekly trap value was independent and represented a replicate sampling of the number of *Ae. albopictus* adults within each site.

Considering previous experience with BGS traps and the number of personnel required to perform a consistent BGS survey, it was decided to deploy nine traps per site in Mercer County and 11 traps per site in Monmouth County. Therefore, 91 BGS traps were deployed weekly during the 2008 mosquito season. Precipitation and temperature data during the trials were obtained from the closest weather station to study sites in Mercer (Trenton weather station) and Monmouth (Tinton Falls weather station) counties.

2.5 Mosquito collection and processing

Because preliminary data indicated that traps in exposed areas collected significantly fewer adult *Ae. albopictus* (Crepeau T *et al*., unpublished), traps were positioned in areas sheltered from direct wind and sunlight as well as from rain. Most of the traps were placed in the far back corner of the yard near vegetation, when possible. After removal from the traps, still in the field, mosquitoes were placed in containers marked with trap number, date and location and transported to the laboratory on dry ice. There, mosquitoes were identified to species and stored at $-80\,^{\circ}$C in labeled polypropylene cryovials (Nalgene®; Daigger, Vernon Hills, IL).

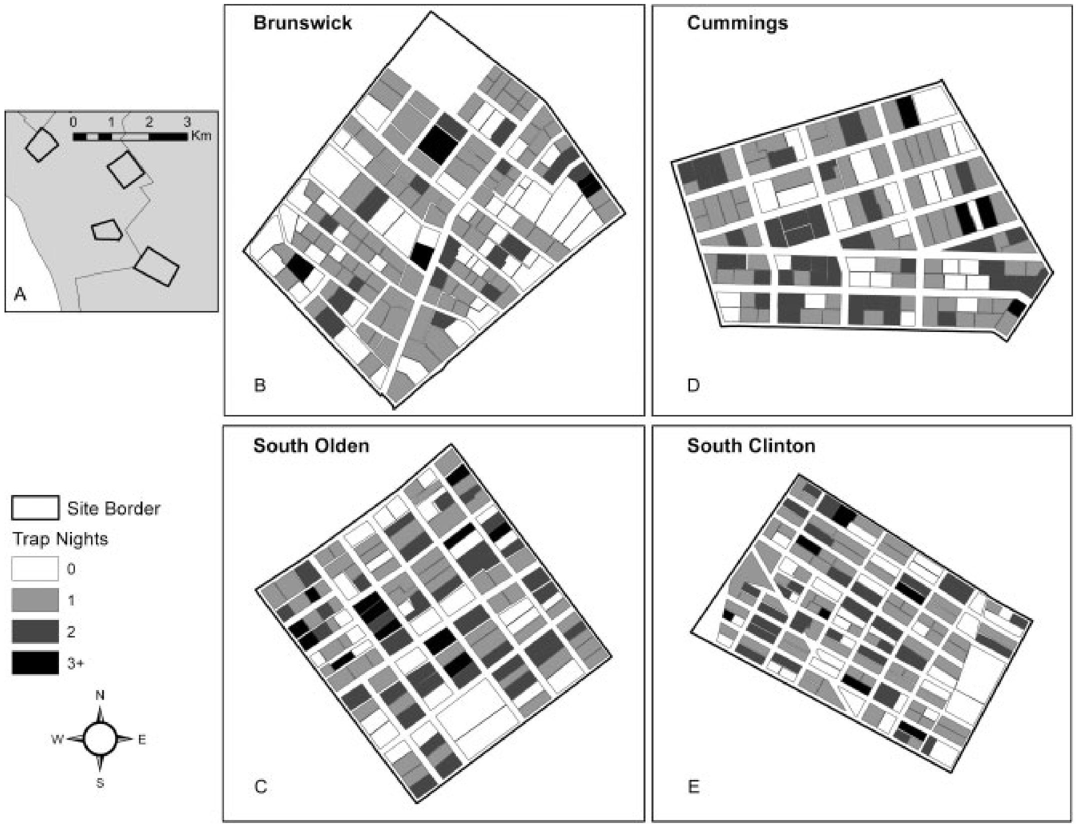

Figure 2. Maps of study sites in Mercer County, New Jersey, 2008. (A) A map showing the locations of four study sites in the Trenton and Hamilton townships. (B) A map of the Brunswick site, showing the trapping frequency; (C) South Olden; (D) Cummings; (E) South Clinton. Shades of grey correspond to the number of times the same grid cell was sampled during the mosquito season.

2.6 Data analysis

High school and college graduation rates, percent of the population living below the poverty level and median income were compared among study sites within each county using analysis of variance followed by Tukey's *post hoc* comparisons (SPSS™, Inc., Chicago, IL). Similarly, the numbers of *Ae. albopictus* were compared among sites within each county using an analysis of covariance (ANCOVA) with time (collection date) as the covariate, followed by pairwise Student's *t*-tests (JMP 8; SAS, Cary, NC). Normality of each weekly distribution was checked with a goodness of fit test, and the analyses were restricted to peak abundance periods to avoid distributions with a significant number of zeroes. Multiple regression analyses were also performed to examine the effects of temperature and humidity on the number of *Ae. albopictus* caught in BGS traps among sites within each county. Finally, the relationship between the average socioeconomic measures (percent high school and college graduation rates and percent population below the poverty level) and the average number of *Ae. albopictus* collected in BGS traps in each site (total number and number of females) was examined.

3 RESULTS

3.1 Initial site selection

In inner-city Trenton the parcel sizes were relatively constant at 200 m^2, and the initial site selection was based mostly on proximity, shape, amount of commercial parcels and elementary school proximity, resulting in four sites (Fig. 2).

Across suburban Monmouth County, however, parcel sizes varied broadly and were on average much larger than those in Trenton. Based on the number of BGS traps available and the need to reproduce the level of coverage possible in Mercer County, the focus was upon the smallest parcels. These parcels were in the 450 m^2 range, and eight potential sites were identified in the municipalities of Aberdeen, Keyport, Union Beach, Keansburg, Middletown, Ocean, Neptune and Freehold Borough. Five of the eight sites were located in the Raritan Bayshore area, two on the Atlantic coast and one in the western part of Monmouth County. An initial demographic examination showed the five Bayshore sites to be more similar, and so the remaining three sites were dropped. Although the smallest parcel sizes were chosen in Monmouth, the selected sites were twice as large as those in Mercer County.

The urban Mercer County study sites were occupied by single-family residences and two-story residential row homes, whereas the suburban Monmouth County study sites included a majority of single-family residences with a few multiple family dwellings. ArcMap's symbology classification statistics provided average, median, maximum and minimum parcel sizes for each site created in each county. Parcel sizes in the study sites were, on average, 199.5 ± 18.3 m^2 in Mercer County and 571.1 ± 31.2 m^2 in Monmouth County, which resulted in study sites ranging from 0.6×0.6 km to 0.9×0.6 km in urban Mercer County, and from 1×1 km to 1.3×1.9 km in suburban Monmouth County.

By means of aerial imagery (New Jersey Office of Information Technology, Office of Geographic Information Systems, https://njgin.state.nj.us/NJ_NJGINExplorer/ShowMetadata.jsp?docId=3733A5AC-B4E9-11DD-828C-0003BA02A824), mean num-

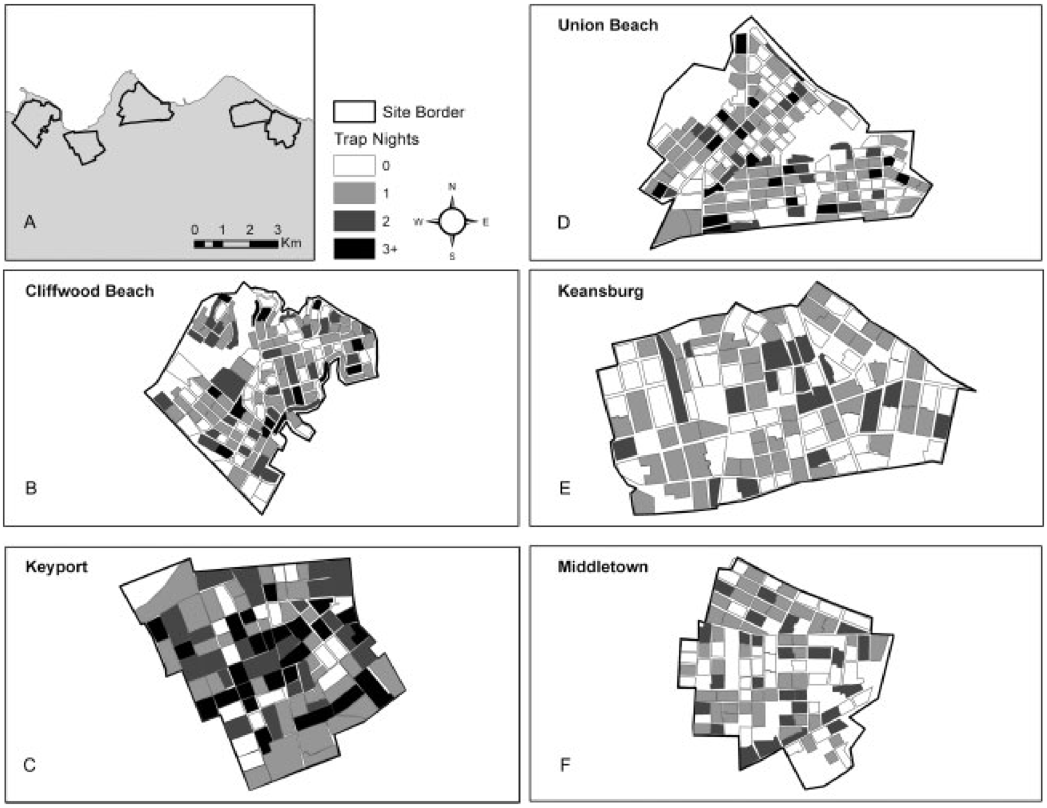

Figure 3. Maps of study sites in Monmouth County, New Jersey, 2008. (A) A map showing the locations of five study sites in the Keyport Bayshore area. (B) A map of the Cliffwood Beach site showing the trapping frequency; (C) Keyport; (D) Union Beach; (E) Keansburg; (E) Middletown. Shades of grey correspond to the number of times the same grid cell was sampled during the mosquito season.

bers of parcels per cell of 8.0 and 9.5 were estimated for Mercer and Monmouth Counties respectively. Within Mercer County, four study sites were selected: 167 grid cells in Brunswick (40° 23′ N, 74° 76′ W), 133 grid cells in South Olden (40° 22′ N, 74° 73′ W), 132 grid cells in Cummings (40° 21′ N, 74° 74′ W) and 139 grid cells in South Clinton (40° 20′ N, 74° 72′ W). Within Monmouth County, five study sites were selected: 146 grid cells in Cliffwood Beach (40° 44′ N, 74° 21′ W), 103 grid cells in Keyport (40° 43′ N, 74° 19′ W), 168 grid cells in Union Beach (40° 44′ N, 74° 17′ W), 130 grid cells in Keansburg (40° 44′ N, 74° 12′ W) and 125 grid cells in Middletown (40° 43′ N, 74° 11′ W). Coordinates were taken in the center of the sites.

3.2 Socioeconomic variables

In Mercer County, the percentage of high school graduates in the population of each potential study site varied from 27.1 to 36.9% (Table 1), and the percentage of college graduates varied from 6.0 to 16.1% (Table 1). In Monmouth County, the percentage of high school graduates in the population of each potential study site varied from 72.2 to 83.1%, and the percentage of college graduates varied from 8.1 to 16.4% in the study sites (Table 1). Poverty rates were much higher in Mercer County than in Monmouth County, as reflected by median annual incomes per parcel in each potential study site of \$30 580–40 000 in Mercer County, as opposed to \$42 000–60 800 in Monmouth County (Table 1).

Although the socioeconomic variables in the study sites within each county were fairly consistent, it was found that the Brunswick site in Mercer County was different from the remaining sites in percent college graduation ($F = 7.1$; df = 3, 24; $P = 0.002$), percent of the population below the poverty level ($F = 4.3$; df = 3, 24; $P = 0.015$) and median income ($F = 3.2$; df = 3, 24; $P = 0.041$) (Table 1). In Monmouth County, Keansburg was also different from Keyport and Middletown for percent high school graduation ($F = 4.485$; df = 4, 32; $P = 0.006$), from Union Beach and Middletown for median income ($F = 4.994$; df = 4, 32; $P = 0.004$) and from all other Monmouth County sites for percentage below the poverty level ($F = 9.125$, df = 4, 32; $P < 0.001$). There were no significant differences between any of the remaining Monmouth County sites for any of the socioeconomic variables (Table 1).

Overall, 71.3% of Brunswick parcels were sampled using randomly placed BGS traps, 76.7% for South Olden, 81.1% for Cummings and 76.9% for South Clinton in Mercer County (Fig. 2, Table 2.). Similarly, 72.6% of parcels were sampled for Cliffwood Beach, 84.4% for Keyport, 63.1% for Union Beach, 63.8% for Keansburg and 73.6% for Middletown in Monmouth County (Fig. 3, Table 2.). Several parcels were sampled more than once (Fig. 2 and Table 2). Some cells in the study sites were never sampled owing to location (school ground) and safety concerns (parks, unoccupied parcels either abandoned or for sale). Initially, teams set up traps in publicly accessed parks, but two BGS traps were stolen in the second week of trapping. Traps were subsequently placed in the backyards of residents who had agreed to participate.

3.3 Mosquito abundance

Each of the nine study sites was visited weekly for targeted sampling from 8 July 2008 to 31 October 2008, at which point the number of *Ae. albopictus* at any of the 91 traps had been zero for two consecutive weeks. Overall, in the four sites in Mercer County, 19 963 mosquitoes were collected using BGS traps, of which

Table 1. Socioeconomic variables for sites in each county. Means (± SE) in a column followed by different upper-case letters are significantly different ($P < 0.05$; ANOVA). Statistical comparisons were performed separately for each county

	Site	Total population	Number of parcels	% High school graduates*	% College graduates	% Below poverty level	Median income ($)
Mercer County	Brunswick	8078	1147	32.1 ± 2.8^{a}	6.09 ± 1.3^{a}	23.67 ± 3.2^{a}	29229.5 ± 3080.3^{a}
	S. Olden	4682	1183	30.5 ± 3.1^{a}	9.7 ± 2.4^{b}	15.35 ± 3.4^{b}	39183.2 ± 2530.6^{b}
	Cummings	8922	1109	27.1 ± 3.2^{a}	12.8 ± 1.6^{b}	12.59 ± 1.6^{b}	35978.7 ± 1644.9^{b}
	S. Clinton	5890	804	36.9 ± 1.1^{a}	16.9 ± 1.4^{b}	12.21 ± 2.3^{b}	40078.8 ± 3452.8^{b}
Monmouth County	Cliffwood Beach	3538	1318	76.0 ± 2.3^{cd}	14.9 ± 3.8^{c}	5.5 ± 2.1^{c}	57523.8 ± 5068.4^{c}
	Keyport	5044	985	83.1 ± 2.1^{c}	16.4 ± 2.3^{c}	6.5 ± 1.2^{c}	47267.4 ± 5254.6^{c}
	Union Beach	4161	1369	77.4 ± 2.5^{cd}	8.1 ± 1.5^{c}	4.5 ± 1.2^{c}	61139.9 ± 2482.7^{c}
	Keansburg	4346	1305	72.2 ± 2.1^{d}	9.1 ± 1.5^{c}	17.3 ± 2.3^{d}	37449.1 ± 2994.1^{d}
	Middletown	4107	1273	82.3 ± 1.3^{c}	13.8 ± 5.8^{c}	7.9 ± 2.3^{c}	56389.0 ± 3813.8^{c}

* Letters a, b, c, d indicate statistical difference: sites with the same letter are not statistically different ($\alpha = 0.05$). Analyses were conducted separately for sites in each county, but, to avoid confusion, a separate set of letters, starting at 'c', was used for Monmouth County.

Table 2. Trapping frequency in the study sites in both counties

	Site	Number of cells	Number of cells sampled once	Number of cells sampled twice	Number of cells sampled ≥3 times	Total % cells sampled
Mercer County	Brunswick	167	94 (56.3%)	20 (11.9%)	4 (2.4%)	70.6
	S. Olden	133	55 (41.4%)	35 (26.3%)	12 (9.0%)	76.7
	Cummings	132	65 (49.3%)	37 (28.0%)	3 (2.3%)	79.6
	S. Clinton	131	65 (46.7%)	34 (24.5%)	7 (5.0%)	76.2
Monmouth County	Cliffwood Beach	146	61 (41.8%)	31 (21.2%)	14 (9.6%)	72.6
	Keyport	103	35 (33.9%)	27 (26.2%)	25 (24.2%)	84.3
	Union Beach	168	66 (39.3%)	21 (12.5%)	19 (11.3%)	63.1
	Keansburg	130	51 (39.2%)	22 (16.9%)	10 (7.7%)	63.8
	Middletown	125	42 (33.6%)	26 (20.8%)	24 (19.2%)	73.6

13 473 were *Ae. albopictus* (67.5%). Additional species caught in Mercer County were: *Ae. (Finlaya) japonicus* (Theobald), *Ae. (Protomacleaya) triseriatus* (Say), *Ae. (Aedimorphus) vexans* (Meigen), *Anopheles (Anopheles) punctipennis* (Say), *An. (Anopheles) quadrimaculatus* Say, *Culex (Melanoconion) erraticus* (Dyar and Knab), *Cx. (Culex) pipiens* L., *Cx. (Culex) restuans* Theobald, *Cx. (Culex) salinarius* Coquillett and *Toxorhynchites (Lynchiella) rutilus septentrionalis* (Dyar and Knab).

Of the 27 814 mosquitoes caught in Monmouth County, 15 007 were *Ae. albopictus* (54%). Besides the mosquito species caught in Mercer County and listed above, additional species caught in Monmouth County were: *Ae. (Ochlerotatus) canadensis* (Theobald), *Ae. (Ochlerotatus) cantator* (Coquillett), *Ae. (Ochlerotatus) sollicitans* (Walker), *An. (Anopheles) crucians* Weidemann, *Coquillettidia (Coquillettidia) perturbans* (Walker), *Cx. (Neoculex) territans* Walker, *Orthopodomyia* (*Orthopodomyia) signifera* (Coquillett), *Psorophora (Grabhamia) columbiae* (Dyar and Knab) and *Uranotaenia (Uranotaenia) sapphirina* (Osten Sacken).

Although BGS traps are designed to capture host-seeking *Ae. albopictus* females, a large number of male *Ae. albopictus* were also collected. Overall, 42.9 and 39.1% of *Ae. albopictus* were males in Mercer and Monmouth counties respectively. Abundances of female and male *Ae. albopictus* were estimated per night per location throughout the study in each county. The peak in *Ae. albopictus* numbers was observed on 5 August (Fig. 4A) in Mercer County, whereas in Monmouth County the highest numbers of *Ae. albopictus* were collected on 29 July (Fig. 4B). Although a small increase in abundance of *Ae. albopictus* populations was observed in both counties in mid-October (Fig. 4), their abundance decreased abruptly in both counties at the end of September 2008.

Examination of the abundance patterns of *Ae. albopictus* across the Mercer County sites (Fig. 4) shows that there were two separate periods of similar abundance: first, a period of highest abundance from 16 July to 27 August, and then a second period in September when abundances were relatively lower but the populations were still high. In the interest of statistical power, it was decided to perform a separate analysis. It was found that, during both time periods, there were statistical differences between sites in the total abundance of *Ae. albopictus* as well as in the abundance of females only, which probably reflect biting rates more accurately (time 1 total *Ae.albopictus*: ANCOVA, $F = 8.68$, df $= 9$, $P < 0.001$; time 1 females: $F = 8.34$, df $= 9$, $P < 0.001$; time 2 total *Ae. albopictus*: $F = 9.10$, df $= 7$, $P < 0.001$; time 2 females: $F = 10.39$, df $= 7$, $P < 0.001$).

During the peak abundance period (mid-July to late August), pairwise Student's *t*-tests ($a = 0.05$, $t = 1.96$) revealed that *Ae. albopictus* was significantly more abundant in Brunswick than in South Olden, and had similar abundance in Cummings and South Clinton (Fig. 5A). During September, South Clinton was not statistically different from South Olden or Cummings, although the latter two differed in abundance. As before, Brunswick had higher numbers of *Ae. albopictus* than the other three sites. The same general pattern of differences and similarities between sites was

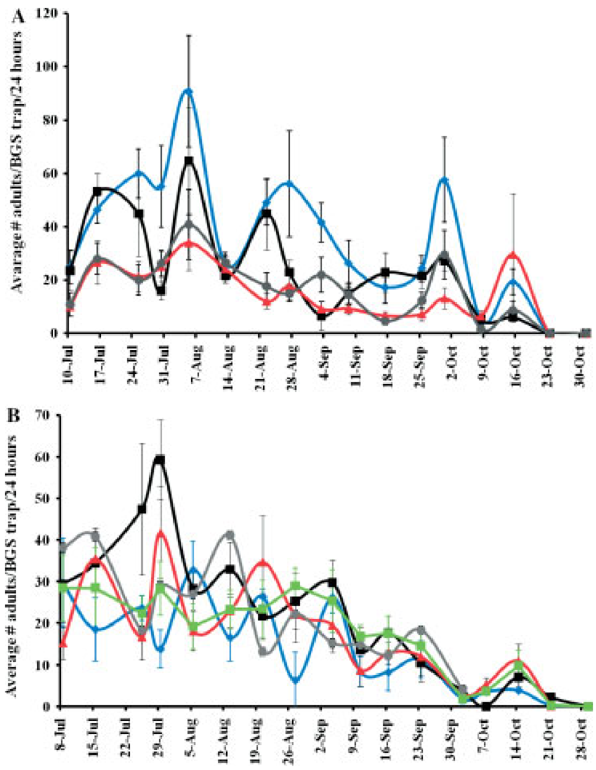

Figure 4. Mean number of adult *Ae. albopictus* per BGS trap (mean per 24 h, both females and males) collected in each study site from July to October 2008 in (A) Mercer County and (B) Monmouth County. In Mercer county: blue line = Brunswick; black line = South Olden; red line = Cummings; grey line = South Clinton. In Monmouth County: blue line = Cliffwood Beach; black line = Keyport; red line = Union Beach; grey line = Keansburg; green line = Middletown.

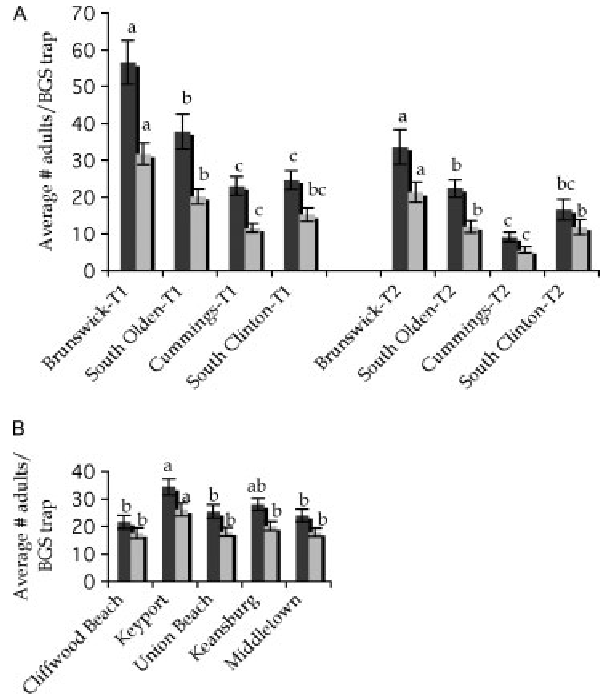

Figure 5. Comparison between sites within each county. Dark-grey bars represent the mean total number of *Ae. albopictus* per BGS trap in each site averaged over each time period; light-grey bars represent the mean number of female *Ae. albopictus* per BGS trap in each site averaged over each time period. In Mercer County: T1 = 16 July to 27 August 2008; T2 = 4–27 September 2008. In Monmouth County the only time period examined ranged from 8 July to 4 September 2008. (A) Mercer County, (B) Monmouth County. Letters above bars indicate statistical significance: sites with the same letter are not statistically significantly different ($\alpha = 0.05$).

repeated when only the abundance of female *Ae. albopictus* was examined (Fig. 5A). Overall, Brunswick had the greatest abundance of *Ae. albopictus*.

In Monmouth County, the abundances of *Ae. albopictus* across the five sites during the peak time from 8 July, when trapping started, to 4 September (Fig. 4) were also significantly different (ANCOVA, $F = 2.6$, df = 12, $P = 0.002$). Pairwise Student's *t*-tests revealed that *Ae. albopictus* was significantly more abundant in Keyport, but the other four sites were equivalent (Fig. 5B). The same result was obtained when comparing numbers of females across sites ($F = 3.83$, df = 12, $P < 0.001$). It was not possible to perform two separate analyses for Monmouth County because abundances in September were very low, with an excessive number of zeroes.

3.4 Effect of temperature

In Mercer County, mean monthly temperatures were 23, 22.7, 20.4 and 14.3 °C during July, August, September and October respectively. In Monmouth County study sites, mean monthly temperatures were 21.2, 21.9, 20.1 and 13.6 °C during July, August, September and October respectively. The relationship between daily average temperature and mean number of *Ae. albopictus* collected in BGS traps was significant at all sites except for Cummings. Regression values for each study site were as follows: Brunswick ($R^2 = 0.37$, $P = 0.012$), South Olden ($R^2 = 0.32$, $P = 0.022$), South Clinton ($R^2 = 0.35$, $P = 0.016$), Cliffwood Beach ($R^2 = 0.56$, $P < 0.001$), Keyport ($R^2 = 0.72$, $P < 0.001$), Union Beach ($R^2 = 0.53$, $P < 0.001$), Keansburg ($R^2 = 0.32$, $P = 0.042$) and Middletown ($R^2 = 0.79$, $P < 0.0001$). Average daily humidity and mean number of *Ae. albopictus* caught in BGS traps were not significantly correlated in any of the sites.

3.5 *Aedes albopictus* abundance and socioeconomic level

Because the flight range of *Ae. albopictus* is considerably larger than a standard backyard in the sites surveyed, and also because socioeconomic levels within each site could vary considerably between neighboring houses (data not shown), an examination was made of the relationship between socioeconomic level and BGS trap numbers by comparing the averages across the nine sites included in the survey. It was found that poverty was positively correlated with number of *Ae. albopictus* captured and accounted for over half the variation ($R^2 = 0.53$, $P = 0.026$, df = 8). However, no other correlation (with percent high school and college graduation or with number of female-only *Ae. albopictus*) was statistically significant.

4 DISCUSSION

The goal was to select three study sites within each county that were similar in socioeconomics and *Ae. albopictus* abundance for use in a project designed to optimize control of this mosquito on an area-wide basis. The mosquito populations were evaluated using BGS traps because these are the most attractive commercially available traps for *Ae. albopictus*. They also have the advantages of collecting mostly *Aedes* mosquitoes (as opposed to *Culex* which are also common in urban and suburban neighborhood) and running continuously for 24 h on a single battery charge.

Instead of using a fixed array of traps surveyed repeatedly over time, it was decided to sample randomly each time across a predetermined grid of cells that included several parcels (homes plus yard). The reasons for this were twofold. First, trap deployment was performed mostly within inhabited parcels with owner approval, which often meant interactions with multiple homeowners. Therefore, it was important for the field crews to have several parcels to choose from in a cell designated *a priori*. Second, by randomly choosing surveillance locations each week, a set of independent evaluations was obtained at each time point of the populations of *Ae. albopictus*, allowing the use of ANCOVA with collection day as a covariate, a more powerful (*sensu* Cohen, 1988[27]) statistical tool than repeated-measures ANOVA.[28]

The objective of this surveillance was not to evaluate *Ae. albopictus* populations across New Jersey or even within the counties. The goal instead was to ensure that the selected sites were equivalent for further experiments. The choice of random surveillance locations at each time point did come at a cost of increasing the variance. That cost was warranted by the decreased likelihood that a few extreme sites might have biased the results if sampled repeatedly over the entire season. The authors endeavored to increase statistical power[27] by collecting as often as possible (17 collections, 13 in the peak active season from mid-July until the end of September, in all sites in both counties).

Two sites (Brunswick in Mercer County and Keansburg in Monmouth County) were eliminated because they had socioeconomic variables that were different from their neighboring study sites. Both these sites had human populations with higher poverty levels, and Brunswick also had significantly lower numbers of college graduates (Table 1). In this study, poverty was positively correlated with the abundance of *Ae. albopictus*, agreeing with previous studies.[19] This is likely because higher numbers of containers are available for egg oviposition and larval development in areas with populations with less education and higher poverty levels.[29] Low socioeconomic variables can also affect educational efforts because the ability to understand written information often correlates with high school and college graduation rates.[30] As the goal of the next phase of the project is to evaluate control efforts by comparing similar areas using different strategies (or no strategy at all in untreated control areas), it was necessary to remove these sites from future studies.

Although the Keyport site in Monmouth County had average socioeconomic parameters, it had a higher abundance of *Ae. albopictus* than the remaining sites and therefore was also removed from consideration. The high abundance of this species in Keyport is of special interest because this was the first location in New Jersey where *Ae. albopictus* was collected during 1995.[8]

In Mercer County, after removing Brunswick, three sites were retained that, although similar socioeconomically, sometimes differed in *Ae. albopictus* abundance. South Olden had higher numbers of *Ae. albopictus* than Cummings, which overall had the lowest abundance. However, South Clinton often had the same numbers of *Ae. albopictus* as the other sites. Faced with the need to maintain three sites, it was decided to use South Clinton as the future control site, where no intervention related to the Asian tiger mosquito project will be deployed in the next phase of the project. South Olden, the site with the highest *Ae. albopictus* abundances, will be the site where most control strategies will be deployed, therefore ensuring that any bias will be conservative and will not affect the ability to identify effective control protocols for *Ae. albopictus*. In Monmouth County, Cliffwood Beach, Union Beach and Middletown were retained for the next phase. As these three Monmouth County sites were equivalent with regard to all variables tested, it is planned to choose one of them randomly as an experimental control, and to perform various treatment interventions in the other two.

On average, the sites chosen in the two counties are quite different. Mercer County sites are typical of dense inner cities, while the Monmouth County sites are middle income and suburban. High school graduation rates were significantly lower ($R^2 = 0.98$, $P = 0.0002$, df $= 5$) and poverty levels were significantly higher ($R^2 = 0.87$, $P = 0.006$, df $= 5$) in Mercer, although average numbers of *Ae. albopictus* were not different, and, interestingly, neither were college graduation rates. This was intentional because, by exploring such obvious differences, it will be possible to develop a broadly applicable and sustainable set of control strategies. It would be good to examine the effect of socioeconomic parameters on mosquito abundance and control more extensively, but the size of the sites that have to be surveyed, as well as the belief that an experimental approach is best, limits the ability to expand the present studies to more sites.

As expected, the analyses showed that high daily average temperature correlated with high BGS trap collections of *Ae. albopictus*. Delays in obtaining enough traps made it necessary to deploy traps in early July, when populations were already high. The early high numbers may be a consequence of the high July 2008 mean temperatures. The yearly trends in abundance of *Ae. albopictus* in these two New Jersey counties were similar, in general, to those observed in Rome, Italy.[31] However, New Jersey populations appear to be more seasonal, as no adults were collected after the second week of October. In addition, mortality rates during October, November and even December in Italian populations of *Ae. albopictus* seem to be lower than in New Jersey, possibly owing to milder temperatures, as ovipositing females persisted until the end of the year. The analyses did not show a correlation between average daily humidity and BGS trap collections in any study sites. It is likely that the lack of association between mosquito abundance and humidity, as well as the relatively low R^2 values between temperature and *Ae. albopictus* abundance, is the result of the low resolution of the climate data. In future surveillance an attempt will be made to make temperature and humidity measures at the scale of the traps.

In addition to obtaining information on the abundance of *Ae. albopictus*, this 4 month surveillance also made it possible to start examining perceptions associated with conducting mosquito surveillance within US cities. While, as expected, inner-city Trenton in Mercer County had high numbers of *Ae. albopictus*, populations were also similarly high in small towns in Monmouth County ($P = 0.26$, $N = 9$ and $P = 0.38$, $N = 5$ before and after outlier sites were removed from the analyses respectively). Furthermore, general access to private property from residents was received well in Mercer County, with compliance rates and acceptance of mosquito control personnel high. The public in inner-city Trenton was very friendly. General acceptance of mosquito control in Monmouth county was also high; however, difficulties in obtaining access within the Monmouth sites were usually associated with mistrust of mosquito control practices, especially the use of insecticides, although these were not being carried or even mentioned by the field crews. One of the critical variables listed by the Grand Cayman Island mosquito control personnel in their comparison of the success rate in controlling *Ae. aegypti* (successfully) and *Ae. albopictus* (unsuccessfully) was the level of engagement of the local citizens.[17] They attributed the current abundance levels of *Ae. albopictus* in Grand Cayman to the lack of awareness by the public of the species' medical importance, and therefore the lack of commitment to its removal. Although the aim is to develop a set of guidelines to control *Ae. albopictus* as a nuisance in New Jersey, and indeed across the United States, an examination will be made of the impact of emphasizing the potential medical importance of this mosquito species[10,13,14] on the likelihood of success of control programs.

Eradication following infestations of *Ae. albopictus* in Mountain View, California (Strickman D, unpublished), and in Indianapolis, Indiana,[16] shows that this species can be successfully eliminated, or substantially reduced, provided the control program is initiated during the early stages of the infestation.[17] In contrast to the California and Indiana populations, which were addressed shortly after they were discovered, *Ae. albopictus* is well established in New Jersey, having arrived 15 years ago. The area-wide approach in the Asian tiger mosquito project is aimed at developing tools to reduce established populations of *Ae. albopictus* to non-nuisance and non-vector levels.

During the next 2 years of the project, all three sites in each county will again be surveyed over the active season while tests are being run on several control strategies including public education, larviciding and, if needed, adulticiding. To assess efficacy, in each county the abundances of *Ae. albopictus* in sites where specific control strategies are being deployed will be compared with those in the control site, where no intervention above and beyond what the local county mosquito control would routinely do will be implemented (see Section 1 for details). Similar strategies will be developed in Mercer and Monmouth counties, although it is already apparent that some customization will be required. Throughout the project, the costs of all control procedures will be documented and an economic analysis will be conducted. The ultimate aim is to use integrated pest management to achieve cost-effective and sustainable control of entrenched nuisance mosquitoes and to demonstrate significant improvements in public health.

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