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DISTRIBUTION OF RESTING FEMALE *AEDES VEXANS* (MEIGEN) IN WOODED AND NONWOODED AREAS OF METROPOLITAN MINNEAPOLIS–ST. PAUL, MINNESOTA

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ABSTRACT. Daytime resting mosquito densities in 4 habitat types (wooded, residential yard, garden, and crop) were examined to determine if areas other than wooded ones may be serving as prime mosquito resting habitat. Adult *Aedes vexans* were collected in the Minneapolis–St. Paul metropolitan area with large battery-powered aspirators to determine mosquito densities at randomly chosen sites within the metropolitan area that supported all 4 habitats. Measurements were taken to estimate the total area of each habitat type within the sample areas. The highest densities of mosquitoes were found in wooded areas. Although agricultural crop areas had relatively low mosquito densities, they supported the 2nd largest number of mosquitoes because of the extremely large cropland area. Residential yards and gardens contained fewer mosquitoes compared with wooded areas. A greater percentage of bloodfed mosquitoes was collected within the wooded habitat.

KEY WORDS Mosquito, *Aedes vexans,* behavior, ecology, habitat, daytime resting

INTRODUCTION

To provide adult mosquito control in an economical and environmentally responsible manner, mosquito abatement personnel need to apply control measures where mosquito densities are highest. The Metropolitan Mosquito Control District (MMCD) in Minnesota applies permethrin as a barrier spray to vegetation in prime daytime mosquito resting areas. Most of the MMCD's permethrin adulticide applications take place in large wooded areas (average size of a permethrin-treated area was 1.23 ha [3.05 acres] in 1993) that provide resting areas for mosquitoes. Less emphasis is put on treating or sampling smaller, nonwooded mosquito harborage areas.

The main target of mosquito control efforts in Minnesota is the pest species *Aedes vexans* (Meigen). Although *Ae. vexans* is known to be a woodland species, it also invades urban and recreational areas and rests in sites containing ferns and rotting timber (Love et al. 1963, Mullen 1971, Horsfall et al. 1973, Bidlingmayer and Hem 1981). Host-seeking females congregate in low vegetation near urban areas, farm buildings, and livestock pastures (Horsfall et al. 1973). *Aedes vexans* is reported to settle in inhospitable terrain fairly effectively and evenly (Dabrowska-Prot 1962). An exhaustive survey of the nonnatural resting areas of this species is lacking in temperate regions (Service 1971, 1977; Irby and Apperson 1992), especially in residential environs.

In addition to residential sites, it is not known if many smaller, nonwooded areas hold as many, or possibly more, mosquitoes as a few larger wooded areas. People who live in residential areas would be more likely to visit or inhabit nonwooded areas where they would encounter *Ae. vexans,* the main cause for annoyance in suburban areas (Horsfall et al. 1973). This study compared *Ae. vexans* resting densities and estimated total *Ae. vexans* numbers collected in nonwooded and wooded areas. The nonwooded areas included agricultural crops, residential gardens, and residential yards.

MATERIALS AND METHODS

Study sites: We randomly chose 3 counties (Washington, Dakota, and Hennepin) from among the 7 counties comprising the Minneapolis–St. Paul metropolitan area (Fig. 1). In each county, 4 areas were selected that contained 3 noncontiguous 2.6 km (1-mi^2) sections with cropland, residential, and wooded habitats in a heterogeneous setting. Areas with large freeway, lakes, urban, or manufacturing areas did not meet the criteria. From these 4 areas within each county, 3 from each county were selected as sample areas.

Using aerial photographs of each area a grid overlay was used to locate 30 randomly generated coordinates. From among these coordinates, we randomly selected 4 each of wooded, garden, crop, and residential yard sites. At each selected site coordinate, the location closest to the coordinate was chosen that corresponded to the designated type of habitat. Wooded areas and agricultural monocrops were at least 0.405 ha (1 acre) in size. Vegetable gardens were represented by small plots in yards, of sufficient size to provide a 2.5-min sample with no sampling overlap. The residential yard habitat type was generally, although not necessarily, limited to ornamental shrubbery and flowers directly adjacent to homes or scattered about the yard. Hedges, small pine trees, and bushes also were included at some yard sites.

Sampling: Sites in each county were sampled at least once per week for 5 consecutive weeks, start-

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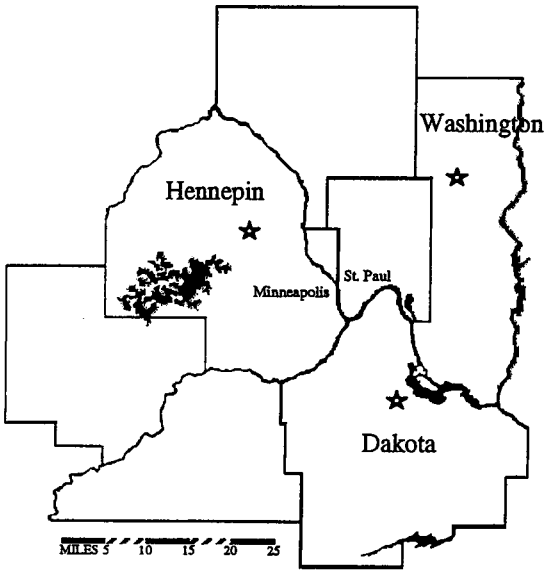

Fig. 1. Location of sample areas, indicated by the stars, in Hennepin, Dakota, and Washington counties in the Minneapolis–St. Paul area of Minnesota.

ing July 8, 1991, and ending August 14, 1991. The sampling day for each county and site order were randomized each week. Mosquitoes were collected from the vegetation between 8:00 a.m. and 1:30 p.m. using a 0.61-m- (2-ft)-diameter, 12-volt, battery-powered aspirator (Nasci 1981). The aspirator had a fully charged battery on every collection date. The time of day, wind speed, temperature, and relative humidity were recorded for each site at the time of sampling.

At each site, the 2.5-min sample was obtained by gently rustling the vegetation with the aspirator. This action provoked resting mosquitoes to fly and increased their likelihood of being collected by this type of area–volume sampler. The swath of the aspirator extended from ground level to approximately 1 m above the ground. This equates to a sample volume of approximately 18.2 × 1.2 × 1 m, or 21.8 m^3 (59 × 3.5 × 3 ft, or 620 ft^3). Adult mosquitoes collected were placed in ethyl acetate killing jars and returned to the laboratory. All female specimens were identified to species; males were only counted.

The percentage of bloodfed mosquitoes was determined by microscopic examination of the abdomen. A mosquito was considered bloodfed if the abdomen showed any trace of blood. The percentage of gravid mosquitoes was estimated by visual inspection under a microscope. A mosquito was considered gravid if the abdomen had traces of eggs, a crude estimation as no specimens were dissected to determine parity, but it did show where a majority of the obviously gravid females were.

Habitat area estimation: Area estimation of each study site was deferred until 1992 because of personnel constraints and a modified experimental design. Wooded areas and agricultural crop habitat types were estimated using both a planimeter and aerial photograph maps. Total residential garden habitat and yard habitat areas were both estimated by physically measuring the volume of vegetation in randomly selected yards that had the possibility of being selected as suitable sites during the mosquito sampling. In each county, the vegetation contents of 10 randomly selected yards were measured for total shrubbery volume, and 10 randomly selected gardens were measured for garden volume estimation. Average amounts of shrubbery in each yard and the average garden size in each of the sample areas of the 3 counties were determined.

Aerial photographs were used to count the number of homes and yards, and an inspection (driving each of the roads) was used to count the total number of gardens in each of the sections sampled. Multiplying the total number of yards by the average yard vegetation provided an estimate of the total volume of yard shrubbery in each 3-section county parcel. Likewise, the average garden size and total number of gardens generated an estimate for total garden volume for each 3-section county parcel. The distance from each sample site to the nearest mosquito breeding site and to the nearest area containing livestock was calculated from distances plotted on aerial photograph maps.

Data analysis: Analysis of variance was used to compare statistical differences in mosquito collection means among the 4 habitat types, and Tukey's honestly significant difference test (SYSTAT 1992) was applied to separate the means where significant differences were calculated. The microclimate parameters and the distance from breeding sites and livestock were checked for significance relative to the mosquito means. A significance level of $P \leq 0.05$ was used. All mosquito totals were $\ln(x + 1)$ transformed to stabilize variance. Mosquito means were used in combination with the habitat area estimation to calculate a total mosquito estimate. This was done for each habitat type, for each county, and for pooled totals.

RESULTS

Female *Ae. vexans* comprised 89% of the 2,899 female mosquitoes and 63% of the 4,102 total mosquitoes collected. Others species collected included *Aedes canadensis* (Theobald), *Aedes cinereus* Meigen, *Aedes dorsalis* (Meigen), *Aedes sticticus* (Meigen), *Aedes triseriatus* (Say), *Aedes trivattatus* (Coquillett), *Anopheles punctipennis* (Say), *Anopheles walkeri* Theobald, *Culex restuans* Theobald, *Culex tarsalis* Coquillett, *Culex territans* Walker, *Culiseta inornata* (Williston), and *Coquillettidia perturbans* (Walker). Female *Ae. vexans,* female *Aedes* species, and the total female mosquitoes were initially analyzed separately, but the results were essentially

Table 1. Estimated habitat areas (acres per square mile) of the 1 mi² sections studied.

Habitat	County			Average
	Hennepin	Washington	Dakota	
Wooded	61.9	110.1	59.7	75.7
Yard	4.2	12.4	1.4	5.8
Crop	50.4	117.3	247.5	129.6
Garden	0.5	0.6	1.7	0.9

the same because female *Ae. vexans* made up the majority of the collections. Because of this, and because *Ae. vexans* is the primary target mosquito in this area, only results for female *Ae. vexans* were reported for this study.

Of the areas sampled, cropland was the most abundant habitat type, followed by wooded areas (Table 1). The disproportionate amount of cropland transformed the low mosquito density into a relatively high total mosquito estimate. The 3 counties were each slightly different in habitat composition, with Washington County supporting large amounts of all habitat types except residential gardens. The areas excluded from the study were generally open grass fields or yards, new construction, commercial buildings or land, roads, or water.

One of the crop sites (a hay field) in Washington County was harvested part way through the summer. This site was eliminated from all analyses, leaving 3 crop sites in Washington County.

Habitat type, county, and temperature each had some degree of influence on the densities of female *Ae. vexans* (Table 2). The wooded habitat type had a higher mean mosquito density (24.33 mosquitoes per 57.6 m²) than the other 3 types, and the garden habitat had a higher mean mosquito density (7.71 mosquitoes per 57.6 m²) than the yard (2.95 mosquitoes per 57.6 m²) or crop (6.00 mosquitoes per 57.6 m²) habitat types (Table 3). The rankings of means were not consistent for the 3 counties because of the inconsistency in the crop and yard habitats of Washington County (Fig. 2).

Even after habitat type was taken into consideration, an examination of the temperature effect (using lowess in SYSTAT [1992]) indicated more mosquitoes were collected at lower temperatures than the model predicted, and fewer mosquitoes than predicted were collected at higher temperatures. Neither weather, distance from breeding sites, distance from livestock areas, nor time-of-day factors influenced numbers of collections of female *Ae. vexans.*

A higher percentage of bloodfed *Ae. vexans* occurred in wooded habitats (13.2%) than in all other habitats (3.1, 5.6, and 4.9% for garden, crop, and yard, respectively) (Table 4). Weather parameters and distance from breeding sites and livestock did not increase or decrease the presence of bloodfed *Ae. vexans* ($P > 0.05$).

From the subsample data presented in Table 1, we estimated a total resting population of 9,727,812 female *Ae. vexans* with 85% of these associated with wooded areas and 15% with crop areas.

DISCUSSION

From subsamples of resting mosquitoes collected from wooded, garden, yard, and crop habitats, wooded areas supported significantly more resting mosquitoes. These results also confirm that resting female *Ae. vexans* in Minnesota select wooded habitats, similar to observations made in Florida by Bidlingmayer (1971) and in New York by Mullen (1971). However, Bidlingmayer et al. (1974) found *Ae. vexans* to be more abundant in fields during the evening hours, which indicates that *Ae. vexans* is perhaps a commuter species traveling between woodlands and sometimes remaining in unfavorable habitat as morning arrives.

The habitat with the 2nd highest mosquito estimate was agricultural cropland. Most of the crops in the sample sites were corn or bean fields, although hay, alfalfa, and soybeans were also in the vicinity of the sampling areas. Horsfall et al. (1973) found that gravid mosquitoes in Illinois may rest in alfalfa fields (and other areas void of sylvan canopy) on their way to oviposition sites, but noted that none were collected between early June and mid-August. This time period is generally the growing season in Minnesota and was the time frame of our study. We found the lowest percentage of gravid mosquitoes in the crop areas in comparison to either wooded or garden habitats.

Exactly where the mosquitoes sampled in this study were moving to or from was unclear, but Horsfall et al. (1973) found that females in the feeding stage concentrate in herbal shade and

Table 2. Results of analysis of variance made on densities of female *Aedes vexans* blocked by habitat type and county.[1]

Source	Sum of squares	df	Mean squares	F-ratio	*P*
Habitat type	124.01	3	41.34	44.87	0.000
County	46.76	2	23.38	25.38	0.000
Habitat type × county	19.33	6	3.22	3.50	0.002
Temperature	4.86	1	4.86	5.28	0.022
Error	218.36	237	0.92		

[1] $n = 250$; $R^2 = 0.468$.

Table 3. Mean density of female *Aedes vexans* with the estimated percentage of total mosquitoes in parentheses of 4 habitat types.[1]

Habitat	County			Pooled total
	Hennepin	Washington	Dakota	
Wooded	52.7 a (87.65%)	14.2 a (92.67%)	10.0 a (57.65%)	24.3 a (84.71%)
Garden	15 b (0.04%)	5.5 b (0.03%)	3.1 b (0.08%)	7.7 b (0.04%)
Crop	13.6 bc (12.23%)	1.3 c (6.16%)	2.6 b (42.19%)	6.0 c (14.93%)
Yard	2.2 c (0.08%)	4.7 bc (1.14%)	1.6 b (0.08%)	3.0 c (0.30%)
Total mosquito estimate	2,139,951	1,310,398	6,277,464	9,727,812

[1] Number per 57.6 m² (620 ft²). Means with same letters in columns were not significantly different ($P > 0.05$).

shrubbery around foundations, barns, and livestock while searching for meals. Brust (1980) also found porcine and bovine hosts to be highly attractive to female mosquitoes. However, this relationship was not investigated in the current study because most of the sampling sites were located in suburban areas, with minimal livestock.

Analysis of our data did not reveal a causal association between resting site locations of *Ae. vexans* and distance to the nearest mosquito breeding sites. Jensen and Washino (1994) found that female *Ae. vexans* readily dispersed from experimental release points, whereas Horsfall et al. (1973) showed that a majority of *Ae. vexans* dispersed from their emergence sites. The observed nighttime movement to daytime resting areas could be attributed to host-seeking requirements, dispersal, or other basic behaviors. The type of daytime harborage or resting area does not tell us why the mosquitoes aggregated there, or even what the nighttime nuisance will be, but it will help direct daytime control activities. Because a lower percentage of gravid mosquitoes was found in the crop habitat, this habitat may have a higher number of host-seeking females.

Analysis of pooled data from each county indicated that wooded sites had a greater percentage of bloodfed mosquitoes than other sites. Although it has been noted that mosquitoes of different physiologic stages do not use different resting areas (Bidlingmayer 1971, Bidlingmayer et al. 1974, Bidlingmayer and Hem 1981), it is possible that some freshly bloodfed species will use the first appropriate resting site encountered (Irby and Apperson 1992). This would indicate that *Ae. vexans* may take blood meals fairly close to the edge of a wooded area.

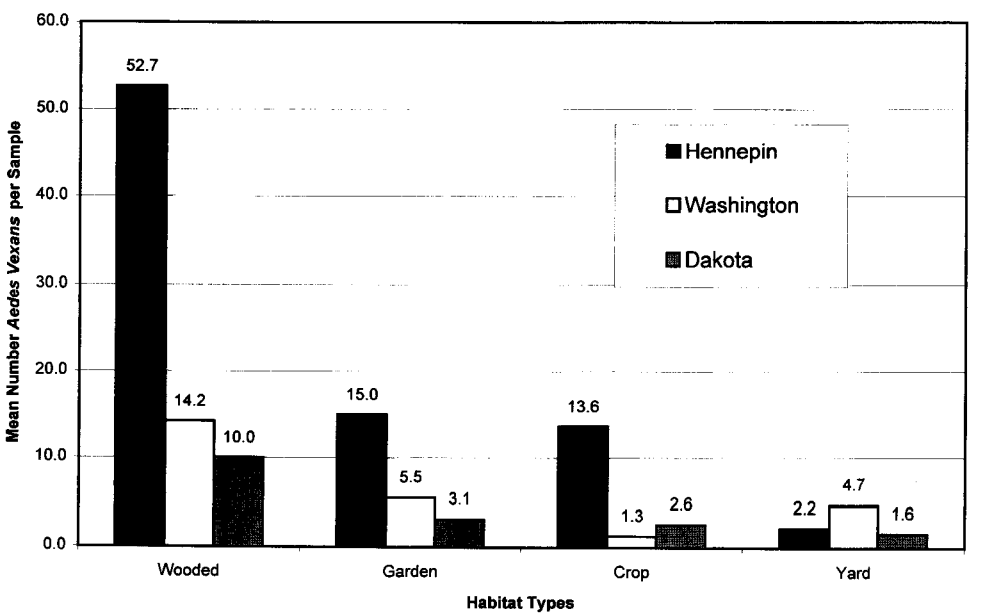

Fig. 2. Mean number of female *Aedes vexans* collected per sample in different habitats of 3 counties in Minnesota in 1991.

Table 4. Mean percent of bloodfed *Aedes vexans* collected in each habitat.[1]

Habitat	County			Pooled total
	Hennepin	Washington	Dakota	
Wooded	10.0 a	11.2 a	18.9 a	13.2 a
Garden	0.6 a	3.5 b	5.3 b	3.1 b
Crop	11.8 ab	2.8 b	2.0 b	5.6 b
Yard	3.8 ab	8.2 ab	2.1 b	4.9 b

[1] Percent is number bloodfed/number total female *Ae. vexans* for each sample. Means with same letters in columns were not significantly different ($P > 0.05$).

The fact that wooded areas contained the highest density of mosquitoes supports our current understanding of an optimal mosquito settlement area. These areas typically support a sylvan canopy and associated dense understory, which the MMCD presently targets for adult mosquito control activities. Although people may be most affected by mosquitoes at their residences, control measures by necessity would be more effective if applied elsewhere. For instance, if many of the smaller harborage types are present in an area, it would be more beneficial (if the purpose of control operations is reducing the overall number of adult mosquitoes) to concentrate control efforts in the fewer, but larger, wooded areas. Although croplands apparently harbor large numbers of mosquitoes, control actions in these habitats would be economically impractical as a consequence of the dispersed nature of the resting mosquito population.

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