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DISPERSAL AND SURVIVAL OF *AEDES ALBOPICTUS* AT A SCRAP TIRE YARD IN MISSOURI

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ABSTRACT. Field-reared *Aedes albopictus* were marked with fluorescent pigment upon release and recaptured with a vacuum aspirator at a scrap tire yard and in surrounding vegetation in Potosi, MO, during 1989–90. In 8 dispersal trials, 8.1% (1,100/13,513) of the *Ae. albopictus* were recaptured with 84.4% (928/1,100) collected in the forest edge ecotone between 10 and 600 m from the release point. The maximum dispersal distance recorded was 525 m and 11.1% (122/1,100) dispersed further than 100 m. In 3 survival trials, 4.8% (2,660/55,284) of the mosquitoes were recaptured. Adult *Ae. albopictus* females survived an average of 8.2 days (probability of daily survival [PDS] = 0.89, range = 0–24) and males an average of 3.9 days (PDS = 0.77, range = 0–12). The dispersal and survival capacity of *Ae. albopictus* adults may contribute to the spread and potential health threat of this mosquito in the USA.

INTRODUCTION

The introduction and spread of *Aedes albopictus* (Skuse) in the United States has been attributed to both an increased traffic in the used tire trade (Reiter and Sprenger 1987) and this mosquito's ability to evolve rapidly and colonize new habitats (Hawley 1988). Following introduction to a site, adult dispersal may allow a mosquito to further expand its distribution.

Dispersal studies have been conducted in Hawaii and Japan (Bonnet and Worcester 1946, Mori 1979). Mori (1979) concluded that adults preferred shaded habitats such as thickets, dispersed an average of 109 m, but few traveled more than 180 m. Wind-aided long distance dispersal is unlikely to occur because *Ae. albopictus* tend to fly close to the ground and avoid flying during strong winds (Bonnet and Worcester 1946). Data from dispersal studies have been used to calculate the field survival rate of *Ae. albopictus* (Mori 1979), but no studies have been specifically designed to estimate their longevity in the field.

Field studies on the field biology of *Ae. albopictus* in its new range were initiated in Potosi, MO, during 1989. Adult dispersal and survival studies were intended to investigate: 1) the distribution of *Ae. albopictus* surrounding an introduction or emergence point, 2) the importance of adult flight in this mosquito's continued spread, and 3) the average lifespan of *Ae. albopictus.* A portion of the mosquitoes collected in this 3-year study were assayed for arboviruses (Francy et al. 1990, Mitchell et al. 1992, Niebylski et al. 1992) and bloodmeals were identified (Niebylski 1992,[1] Savage et al. 1993). Considering the results together, inferences on the potential health threat of this mosquito in the United States may be made.

MATERIALS AND METHODS

The study site was a scrap tire yard and surrounding habitat in Potosi, MO, described previously (Francy et al. 1990, Savage et al. 1993). The sampling area encompassed 3 distinct habitats: forest edge ecotone with dense understory (type A), inner forest with sparse understory (type B), and open tire yard with minimal vegetation (type C). The forest edge surrounded the tire yard and contained numerous tire casings shrouded by vegetation.

Dispersal: Field-reared *Ae. albopictus* were subjected to a series of single mark, multiple recapture experiments to evaluate their dispersal. Fourth-generation *Ae. albopictus* (Potosi strain) and field-collected larvae were reared to pupation in tire casings and ceramic pans. A maximum of 250 larvae was reared together in 2 liters of filtered tire water and fed a suspension of liver powder in water (Munstermann and Wasmuth 1985). Each container was supplemented with 5 freshly killed, whole crickets (*Gryllus* sp.) and approximately 5.0 g crushed oak (*Quercus* sp.) and maple (*Acer* sp.) leaves. Tap water was periodically added to account for the amount lost via dehydration. Wing measurements (from the base of the costa to the tip of the wing) of field-reared female mosquitoes were used as an index of larval nutrition (3.0 ± 0.20 mm, n = 120).

Pupae were counted and transferred to a self-marking device (Niebylski and Meek 1988) in the forest edge (type-A habitat). Emergent adults were labeled with fluorescent pigment (Day-Glo Color Corp., Cleveland, OH) upon exiting the device. Preliminary field trials determined that the device labeled 100% of exiting mosquitoes and pigment was detectable for 30 days. The

[1] Niebylski, M. L. 1992. Bionomics of *Aedes albopictus* (Skuse) in Potosi, Missouri. Ph.D. dissertation. University of Notre Dame, Notre Dame, IN.

number of marked–released mosquitoes was determined by subtracting the number of adults and pupae remaining in the device on Day 0 from the number of pupae initially placed beneath the marking device 32 h earlier. In 7 successive trials, 964, 1,312, 1,518, 1,965, 1,143, 418, and 2,128 *Ae. albopictus* were marked–released during May–October 1989 and May–June 1990. The sampling area (300 × 300 m) with 36 quadrats (50 × 50 m) surrounded a centrally located marking device. Eleven, 16, and 9 quadrats were located in type-A, -B, and -C habitats, respectively.

An 8th dispersal trial was conducted during September 1990 to determine if location of emergence influenced dispersal patterns. In trial 8, field-reared *Ae. albopictus* were simultaneously released in each of 3 habitat types; 1,274 (release 1) along the forest edge adjacent to the tire yard, 1,328 (release 2) in the forest (type-B habitat), and 1,463 (release 3) in the middle of the tire yard 100 m from the nearest thicket. Release 2 was 10 m from the forest edge and 50 m from the tire yard. A different pigment was employed for each release and the study area was enlarged to 1,200 × 1,200 m with 148 quadrats (50 × 50 m). Inaccessible locations were not sampled. Sixty-five, 38, and 45 quadrats were located in type-A, -B, and -C habitats, respectively.

Adult mosquitoes were collected with a vacuum aspirator (Nasci 1981) operated for 10-min intervals. After 8 trials, 208 quadrat samples were made 3–16 days postrelease on 25 collection dates. Mosquitoes were stored on wet ice in the field, sorted on a chill table, and examined under a high-intensity, 366-nanometer, ultraviolet lamp (Model b-100A, VWR Scientific, Chicago, IL) and stereomicroscope for evidence of pigment. Dispersal distances for each recaptured mosquito were recorded as the shortest distance from point of release to the quadrat from which it was collected.

Landing/biting *Ae. albopictus* were collected with a hand-held aspirator (Perdew and Meek 1990) operated for 5-min intervals during May 1989–September 1990. A minimum of 3 quadrats in each habitat was randomly sampled on 8 collection dates. Relative humidity and air temperature were monitored with a protimeter diagnostic hygrometer (Unit MK IV, Forestry Suppliers, Inc., Jackson, MS). Five measurements were taken 15–30 cm above the ground per habitat on each of 5 sampling dates.

Survival: A single mark, multiple recapture method was also used to estimate mosquito survival during June–September 1990. Approximately 120,000 3rd and 4th generation *Ae. albopictus* (Potosi strain) eggs were hatched and mass-reared in the field as described previously. Rearing containers were housed within a screened tent. Wing lengths of field-reared female mosquitoes were measured (2.95 ± 0.17 mm, n = 90). In successive trials, 22,180, 15,483, and 17,621 *Ae. albopictus* were marked–released with a marking device in the forest edge. Mosquitoes were recaptured with a vacuum aspirator operated for 5-min intervals. Eighteen quadrats (25 × 25 m) located within the forest edge were randomly sampled on 5 collection dates per trial. Sixty-nine quadrat samples were made 5–24 days postrelease in trial 1, 83 quadrat samples were made 4–20 days postrelease in trial 2, and 82 quadrat samples were made 4–21 days postrelease in trial 3. Specimens were examined for evidence of pigment as described previously.

Following the protocol of Macdonald (1957), Gillies (1961), and Walker et al. (1987), the regression of the $\log_{10}$(recaptures + 1) on day postrelease was used to calculate the probability of daily survival (PDS) and average lifespan expectancy (ALE) of *Ae. albopictus* adults.

RESULTS

Dispersal: After 8 trials, 8.1% (1,100/13,513) of the *Ae. albopictus* were recaptured and 84.4% (928/1,100) dispersed to a forest edge ecotone. Location of emergence had no apparent impact on dispersal patterns. The maximum dispersal distance was 525 m by an *Ae. albopictus* female and 225 m by an adult male.

Mark–release–recapture data from trials 1–7 were pooled and analyzed. In trials 1–7, 6.4% (602/9,448) of marked–released *Ae. albopictus* were recaptured (Table 1). Of these, 84.9% (511/602, n = 52) were recaptured within 100 m of the release point and 15.1% (91/602, n = 66) were recaptured 100–212 m away. The majority of the mosquitoes dispersing less than 100 m (444/511) and beyond (72/91) were collected from the forest edge habitat.

A one-way analysis of variance (ANOVA) comparing collections between habitats revealed a significant difference in the number of females ($P < 0.01$) recaptured. Similarly, there was a significant difference in the collection of unmarked females ($P < 0.005$), marked males ($P < 0.01$), and unmarked males ($P < 0.005$) (Table 1).

A one-way ANOVA comparing collections between habitats from trial 8 also revealed significant differences (Table 1). During trial 8 (releases 1, 2, and 3), 12.1% (498/4,065) of released mosquitoes were recaptured (Table 1). Of these, 93.8% (467/498, n = 19) were collected within 100 m of the release point and the remaining 6.2% (31/498, n = 38) were recaptured 100–525 m away. Further, 80.0% (60/75), 86.6% (58/67), and 78.0% (53/68) of recaptured females from

Table 1. Summary of 8 successive mark–release–recapture trials to evaluate adult *Aedes albopictus* dispersal within 3 habitats at a Potosi, MO, study site during 1989–90.

Trial	Habitat type[2]	Number released[3]	Number of quadrat samples[4]	Number of *Ae. albopictus* collected			
				Females[1]		Males[1]	
				Unmarked	Marked	Unmarked	Marked
1–7	A		46	4,049	296	4,654	217
	B		66	1,398	45	1,188	35
	C		39	247	4	216	5
	Overall	9,448	151	5,694	345	6,058	257
8	A	1,274	18	1,879	171	2,023	244
	B	1,328	24	390	35	311	38
	C	1,463	15	68	4	78	6
	Overall	4,065	57	2,337	210	2,412	288
Total	A		64	5,928	467	6,677	461
	B		90	1,788	80	1,499	73
	C		54	315	8	294	6
	Overall	13,513	208	8,031	555	8,470	545

[1] A one-way ANOVA comparing collections between habitats found a significant difference for unmarked females ($P < 0.005$), marked females ($P < 0.01$), unmarked males ($P < 0.005$), and marked males ($P < 0.01$). Results from trials 1–7 were pooled and analyzed separately from results from trial 8.

[2] The 3 distinct habitats sampled were type A (forest edge ecotone with dense understory), type B (inner forest with sparse understory), and type C (open tire yard with minimal vegetation).

[3] In trials 1–7, mosquitoes were marked–released with a centrally located self-marking device positioned between type-A and type-B habitats. In trial 8, mosquitoes were marked–released with 3 separate pigments in each of the 3 habitat types.

[4] Quadrats (50 × 50 m) were randomly sampled with a vacuum aspirator operated for 10 minutes per quadrat. Collections were made on 25 sampling dates for all 8 trials. The sampling area was enlarged from 300 × 300 m to 1,200 × 1,200 m for trial 8.

releases 1, 2, and 3, respectively, were collected in type-A habitat. In the forest edge, there was no significant difference (one-way ANOVA, $P >$ 0.1) between the collection of marked females from the 3 simultaneous releases. Similarly, there was no significant difference between the number of females or males from releases 1, 2, and 3 recaptured within any of the 3 habitat types (one-way ANOVA, $P > 0.1$, in all cases).

Landing/biting rates ($n = 38$, mean = 18.2 females/min, range = 2–48) were most intense in the forest edge (type-A habitat). Fewer mosquitoes fed in type-B ($n = 46$, mean = 10.6 females/min, range = 0–32) and type-C ($n = 15$, mean = 2.1 females/min, range = 0–10) habitats. A comparison of relative humidity among habitats on a given sampling date found no significant difference ($P > 0.5$, one-way ANOVA, in all cases). Temperature was also uniform in the 3 habitats on all sampling dates ($P > 0.5$, one-way ANOVA, in all cases).

Survival: In 3 survival trials, 4.8% (2,660/55,284) of the released *Ae. albopictus* were recaptured. A single marked *Ae. albopictus* female was recaptured 24 days postrelease, the maximum lifespan recorded. Male mosquitoes survived up to 12 days postrelease. Only collections made prior to day 14 postrelease were used to calculate male survival rates. Survival rates for *Ae. albopictus* females (mean PDS = 0.89, ALE = 8.2 days) and males (mean PDS = 0.77, ALE = 3.9 days) for 3 trials are summarized in Table 2. The sample size (n), slope of the regression line (b), standard error of the mean for the slope of the regression line (SEM of b), coefficient of determination (r^2), correlation coefficient (r), significance probability (P), and number of recaptures (M) were also calculated (Table 2). The antilog$_{10}$ of b was the PDS and $1/-\log_e$PDS was the ALE. Slopes of the regression lines were all significantly different from 0 ($P < 0.001$) and correlation coefficients all exceeded 0.67 (Table 2).

DISCUSSION

Dispersal via short-range flight may contribute to the spread of *Ae. albopictus,* as seems to have occurred in Florida (O'Meara et al. 1993). Logically, *Ae. albopictus* would colonize new habitats surrounding an infestation focus such as a tire yard or cemetery. However, factors such as the availability of water-holding containers and suitable habitat may limit the sequential spread of this species from infestation foci. The mosquito population has the potential to expand its dis-

Table 2. Summary of *Aedes albopictus* adult survival rates and regression analysis for 3 successive mark-release-recapture trials conducted at a study site in Potosi, MO, during June–September 1990.

	Females				Males			
	Trial				Trial			
Statistic[1]	1	2	3	Mean	1	2	3	Mean
PDS[2]	0.87	0.89	0.89	0.89	0.76	0.78	0.78	0.77
ALE[3]	7.5	8.77	8.5	8.2	3.6	4.0	4.0	3.9
n[4]	69	83	82		59	54	47	
b	−0.051	−0.050	−0.058		−0.106	−0.108	−0.119	
SEM of *b*	0.007	0.006	0.005		0.005	0.005	0.006	
r^2	0.731	0.683	0.809		0.676	0.897	0.830	
r	0.855	0.826	0.899		0.822	0.947	0.911	
a	1.521	1.472	1.578		1.522	1.515	1.638	
P	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001	
M[5]	572	699	651		280	208	250	

[1] Statistics were probability of daily survival (PDS), average life expectancy (ALE), sample size (*n*), slope of regression line (*b*), standard error of the mean for the slope of the regression line (SEM of *b*), coefficient of determination (r^2), correlation coefficient (*r*), y-intercept (*a*), significance probability (*P*), number of recaptures (M).

[2] PDS was calculated as the antilog$_{10}$ of *b* for (no. recaptured + 1) on day of recapture, postrelease.

[3] ALE was calculated as 1/−log$_e$PDS and expressed in days.

[4] The sample size (*n*) was the number of quadrat samples made on 15 collection dates (5 per trial) between 4 and 24 days postrelease.

[5] The number of recaptures (M) represents a portion of those initially released. Overall, 22,180, 15,483, and 17,621 *Ae. albopictus* were marked–released in trials 1, 2, and 3, respectively.

tribution 100 m every mosquito generation. More than 10% dispersed further than 100 m and a few flew as far as 525 m. Similarly, *Ae. albopictus* released on a Pacific atoll flew up to 600 m (Rosen et al. 1976) but generally traveled less than 200 m in other studies (Bonnet and Worcester 1946, Mori 1979).

In Potosi, *Ae. albopictus,* regardless of the habitat in which they emerged, dispersed primarily to a forest edge ecotone, which supports the findings of Mori (1979). The mosquitoes maximized their ability to obtain sugar and blood by selecting the habitat where flowers, mammals, and birds were abundant. Here, *Ae. albopictus* were observed feeding on goldenrod (*Solidago* sp.) nectar, landing/biting rates reached their peak, and the majority of bloodfed specimens were collected. The dense vegetation may also have provided protection from wind and sunlight. Similarly, Beier et al. (1982) reported that *Aedes triseriatus* (Say) adults preferred the forest edge. Vertical distribution of *Ae. albopictus* remains an issue.

Adult *Ae. albopictus* female survival rates (ALE = 8.2, PDS = 0.89, maximum lifespan = 24 days) far exceeded those (ALE = 3.8–4.8 days, PDS = 0.77–0.81) reported previously (Hawley 1988) but were still below that for *Ae. triseriatus* females (ALE = 11.6 days, PDS = 0.92) (Walker et al. 1987). In Potosi, *Ae. albopictus,* assuming an average gonotrophic cycle of 4 days (Hawley 1988), may have survived long enough to bloodfeed twice. Although unlikely, the female surviving 24 days may have fed 5 times.

The longer survival of *Ae. albopictus* females recorded in Potosi may have been due to an innocuous self-marking device that labels emergent mosquitoes without handling or manipulating them as in other techniques. A second reason is that the released mosquitoes, based on moderate to above average wing lengths, may have been well nourished with a sufficient fat reserve to survive longer periods. If this was the case, the mosquitoes would also have had a capacity to disperse longer distances and a reduced desire to bloodfeed. Another explanation for their extended lifespan is that bloodfeeding and subsequent oviposition, 2 potentially stressful and lethal events, were delayed in the field. Hosts may have been periodically scarce, as indicated by mammal collections at the site, and *Ae. albopictus* may have been unable to readily bloodfeed. Interestingly, the search for blood hosts may have stimulated *Ae. albopictus* to disperse farther.

Mortality during oviposition was documented in Potosi where dead *Ae. albopictus* adults were common on oviposition papers and the water surface within tire casings. Predation by spiders was another cause of death observed in Potosi and has been noted previously (Ori 1974).

As a mosquito species adapted to transition habitats, *Ae. albopictus* may potentially be exposed to arboviruses in sylvatic habitats and transmit them to vertebrates in nearby, more urban areas. For example, at 3 study sites in E. St. Louis, IL, *Ae. albopictus* were collected from small lots overgrown with vegetation, surrounded by human residences and where trash was discarded. At these urban dumps, bloodfed mosquitoes were readily collected (n = 149/130 min) and rats and rabbits were the primary hosts (Niebylski 1992[1]). Far fewer bloodfed mosquitoes were collected in Potosi (n = 15/180 min) and at 6 sites in Florida, Illinois, Indiana, and Louisiana (n = 93/1,040 min). The potential for urban blood hosts such as Norway rats (*Rattus norvegicus*) to serve also as hosts for arboviruses requires further investigation.

CONCLUSION

Mark–recapture field trials in Potosi, MO, provided insight into the ecology of *Ae. albopictus* in its new range. This mosquito dispersed beyond points of introduction to colonize transition habitats, particularly areas with dense vegetation and water-holding containers. They also survived long enough to bloodfeed more than once. These findings, coupled with this species' susceptibility to endemic arboviruses and opportunistic bloodfeeding behavior, indicate *Ae. albopictus* has the potential to be an established vector and nuisance pest. Continued surveillance and personal protection is important where *Ae. albopictus* infestations occur.

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