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EVALUATION OF A NOVEL EMERGENCE TRAP TO STUDY *CULEX* MOSQUITOES IN URBAN CATCH BASINS

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ABSTRACT. Stormwater catch basins in urban areas provide important larval habitat for *Culex* mosquitoes. In this study we quantified adult *Culex* emergence using a newly designed emergence trap deployed in catch basins in suburban Chicago, IL. Traps were deployed from late June to mid-October, 2009–10, in 19 catch basins for a total of 461 trap-days. Based on laboratory trials, the percentage of adults emerging under the trap and reaching the collection cup ranged from 37.7 ± 6.5% for closed-cup and 50.5 ± 3.8% for open-cup configurations. In 2009, catch basins containing immature mosquitoes produced an estimated 58.9 ± 30.8 female and 86.2 ± 36.4 male *Culex* spp. per day. Most (84.4%) were *Culex pipiens* and the remainder were *Cx. restuans*. The trap was also effective in documenting reductions in adult emergence following intense precipitation events that caused "flushing" of larvae and pupae. In general, the new emergence trap was effective for studying *Culex* production in catch basins and should be broadly useful in studies of container-breeding mosquitoes.

KEY WORDS Catch basins, *Culex pipiens*, emergence trap, production, West Nile virus

INTRODUCTION

Stormwater treatment systems utilizing catch basins are ubiquitous in the USA and are known sources of mosquito production in the urban environment (Munstermann and Craig 1976, Geery and Holub 1989, Su et al. 2003, Anderson et al. 2006). The principal mosquito species occupying these habitats are *Culex* spp. (Kronenwetter-Koepel et al. 2005, Rey et al. 2006), the primary enzootic vectors of St. Louis Encephalitis (Tsai and Mitchell 1989) and West Nile virus (Marra et al. 2004). In an effort to reduce arboviral transmission to humans, catch basins are often treated for mosquito abatement with larvicidal oils (Geery and Holub 1989), and long-lasting formulations of *Bacillus sphaericus* Neide (Siegel and Novak 1997), *Bacillus thuringiensis* (Berliner) serovar. *israelensis* de Barjac (Phillips et al. 1991), and S-methoprene (Baker and Yan 2010).

Although many studies have characterized the mosquito communities in catch basins and the influences of biotic and abiotic factors on the presence of immature mosquitoes in these structures (Su et al. 2003, Kronenwetter-Koepel et al. 2005, Rey et al. 2006), very few studies have attempted to estimate the contribution of catch basins to the total population of *Culex* spp. The presence of immature mosquitoes in catch basins does not imply subsequent emergence given that methoprene-based larvicides prevent adult eclosion and rain is known to flush immature mosquitoes (Koenraadt and Harrington 2008). Traditionally, emergence from catch basins has been measured by subsampling pupae and allowing pupae to emerge into adults in the laboratory. While this approach is effective for measuring efficacy of larvicide (Stockwell et al. 2006, Baker and Yan 2010), it does not provide realistic estimates of the total number of mosquitoes emerging from catch basins. Previous studies have deployed adult mosquito traps in catch basins (Su et al. 2003, Anderson et al. 2006, Molaei et al. 2007), but these traps also collect oviposition-seeking females and resting adults, which complicates extrapolation to the emergent population. For these reasons, emergent traps, which subsample the emergent populations directly, are necessary to estimate adult production from catch basins.

Emergence traps have been used in mosquito studies in diverse larval habitats such as wetlands (Appleton and Sharp 1985, Castleberry et al. 1989, Walton 2009), wastewater treatment impoundments (Castleberry et al. 1989), rice fields (Mwangangi et al. 2008), septic tanks (Burke et al. 2010), and latrines (Girikumar and Rao 1984). In the current study we evaluated a newly designed emergence trap that subsamples emerging adult mosquitoes in catch basins. The objectives of this study were to utilize the emergence trap to 1) detect emergence given uncertainty associated with mosquito abatement effort and larvicide efficacy, 2) extrapolate emergence trap data to estimate total *Culex* emergence, and 3) identify the influence of rain events on mosquito population dynamics. In

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Fig. 1. Emergence traps next to a catch basin. The trap on the left is constructed of black plastic and the trap on the right is constructed of stainless steel mesh; all data presented in this study utilized the steel mesh trap style. The collection cup on the left is a closed inverted cup, while the cup on the right includes a removable lid with a screen mesh top.

order to estimate total *Culex* emergence from catch basins per unit area, we determined the density of catch basins in our study region at 11 residential sites and monitored them for the presence of immature *Culex* mosquitoes. Relative abundance of *Culex* mosquitoes was obtained using CO_2-baited Centers for Disease Control and Prevention (CDC) miniature light traps.

MATERIALS AND METHODS

Trap design

A conical emergence trap was designed incorporating characteristics of previous designs (Silver 2008) and consisting of a stainless steel mesh cone affixed to a buoyant foam tube (Fig. 1). The apex of the trap holds a collection cup, which is an inverted 500-ml plastic jar with a stainless steel nonreturn entrance cone. The lid of the collection cup is permanently attached to the top of the trap, which allows the collection cup to be removed by the screw lid. Two collection cup designs were evaluated, one that was closed and one that contained a removable cap with a stainless steel screen (Fig. 1). The dimensions of the trap are 35 cm in diam as measured by center of foam and 30 cm in height (covers surface area of 0.96 m^2). The volume in the trap is 9,733 cm^3. In addition to traps made with stainless steel mesh, we also evaluated a trap made with black high-density polyethylene plastic (0.89 mm thick; Fig. 1).

Catch basin density

The average number of catch basins per hectare was measured beginning in 2005 at a total of 11 residential locations (Hamer et al. 2008; site numbers 1–12 except 4). We surveyed all residential sites on foot and all catch basins were geocoded using a handheld geographical positioning system recorder. A random subsample of 20 catch basins from each site was sampled 4 times for immature mosquitoes between early July and early September 2005. Samples were collected using a 10.2 × 10.2-cm aquarium net attached to the end of a conduit pole, 3 m in length and 1.3 cm in diam. Each sampling consisted of a standardized figure-eight sweep and all larvae and pupae were enumerated. A subsample of 5–10 4th instars per sample were identified to species (Andreadis et al. 2005).

Laboratory experiments

We conducted laboratory experiments to determine the efficiency of the trap for collecting emerging adults, given that not all mosquitoes that emerge under the trap reach the collection cup (Corbet 1965, Castleberry et al. 1989, Walton 2009). The trials were done in a Percival Scientific (Perry, IA) incubator at 16:8 h light:dark and 25°C. We simulated the catch basin light environment by placing the emergence traps on a cardboard platform and with a cardboard box surrounding the entire trap, except that we allowed the top of the collection cup to protrude. Duct tape was used to seal the edges of the cardboard. This design prevented light from entering the sides of the trap to simulate the light entering the top of a catch basin. We placed up to 50 individual *Culex pipiens* f. *molestus* Forskål pupae from a laboratory colony into cups with deionized water under the emergence traps. Castleberry et al. (1989) determined the time necessary to reach maximum trap efficiency for mosquitoes in the collection cup of emergence traps was 8 days. At the end of 8 days, we counted the number of adult mosquitoes in the collection cup and the numbers that had died before entering the cup. We evaluated trap efficiency for both styles of the collection cup, and efficiencies are presented as the percentage of adults in the collection cup divided by the total number of emerged adults.

Field experiments

We deployed emergence traps in catch basins between mid-July to mid-September, 2009, and late June to mid-October, 2010, in Alsip and Palos Hills, IL, a region with high annual West Nile virus transmission (Hamer et al. 2008, 2009). In 2009, we placed emergence traps in a total of 15 catch basins for between 1 and 5 days for a total of 37 trap-days. In 2010, we deployed 4 emergence traps in 4 catch basins and monitored them approximately weekly (checking interval range of 2–10 days; a total of 424 trap-days). Additionally, in 2010 we performed paired field trials to evaluate the different trap types (black plastic versus stainless steel mesh) by placing the 2 trap types in the same catch basin at

Table 1. Results of field trials of emergence traps in catch basins in Alsip and Palos Hills, IL, 2009. Final column is the extrapolated estimate of the number of *Culex* mosquitoes emerging from catch basins per day.

		No. in cup		No. in cup/day		Corrected no. in cup/day[1]		No. emerging outside of trap[2]		No. emerging from catch basin/day	
Date deployed	Hours set	♂ *Culex*	♀ *Culex*	♂ *Culex*	♀ *Culex*	♂ *Culex*	♀ *Culex*	♂ *Culex*	♀ *Culex*	♂ *Culex*	♀ *Culex*
13 Jul.	48.5	21	12	10.39	5.94	27.55	15.74	46.22	26.41	73.77	42.15
13 Jul.	47.0	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15 Jul.	48.0	2	0	1.00	0.00	2.65	0.00	5.09	0.00	7.74	0.00
15 Jul.	48.5	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20 Jul.	43.0	19	16	10.60	8.93	28.11	23.68	507.22	427.13	535.33	450.80
20 Jul.	48.0	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29 Jul.	90.5	130	67	34.48	17.77	91.40	47.10	153.34	79.03	244.73	126.13
29 Jul.	116.8	65	15	13.36	3.08	35.42	8.17	72.50	16.73	107.92	24.91
5 Aug.	48.5	5	3	2.47	1.48	6.56	3.94	13.42	8.05	19.98	11.99
5 Aug.	47.0	32	46	16.34	23.49	43.32	62.27	72.68	104.47	116.00	166.75
12 Aug.	48.0	1	0	0.50	0.00	1.33	0.00	2.55	0.00	3.87	0.00
12 Aug.	48.5	10	1	4.95	0.49	13.12	1.31	23.59	2.36	36.71	3.67
14 Aug.	43.0	3	1	1.67	0.56	4.44	1.48	49.66	16.55	54.10	18.03
11 Sept.	48.0	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11 Sept.	117.0	14	6	2.87	1.23	7.61	3.26	85.17	36.50	92.78	39.76
Mean	59.35	20.13	11.13	6.58	4.20	17.43	11.13	68.76	47.82	86.20	58.95

[1] Corrected number given that not all mosquitoes emerging under the trap end up in the collection cup (37.7% recovered in closed cup and 50.5% in open cup).

[2] Estimated number of *Culex* emerging from catch basin from outside of trap assuming homogeneous distribution of pupae. Percentage of area covered by trap ranged from 5.2% to 37.3% (mean of 25.7%).

the same time. Only catch basins containing immature mosquitoes were used in the field trials in 2009. Steel manhole cover hooks were used to remove the grated catch basin lid, and emergence traps were tied to the catch basin lid to hold the trap upright in the event of rainwater flow. Mosquitoes captured in the collection cup were killed with dry ice and sorted by sex and species (Andreadis et al. 2005). Although the majority of adult *Culex* were identified morphologically as *Cx. pipiens* (84.4%), we grouped *Culex* spp. mosquitoes together for the analysis because *Cx. pipiens* and *Cx. restuans* Theobald are difficult to distinguish morphologically (Harrington and Poulson 2008). To assess relative *Culex* abundance in the study region, we operated CO_2-baited CDC miniature light traps in 51 locations that were operated weekly in the same study region in 2009 and 100 light trap locations in 2010. Mosquitoes were sorted by species (Andreadis et al. 2005), and *Culex* abundance data presented for both years are means of light trap data collected from early July to late September. In 2010, we deployed a Hobo weather station (Onset Computer Corporation, Pocasset, MA) placed 1.5 km from the catch basins to acquire precipitation data. All means are presented ± standard error, and statistical analysis was performed using Program R (R Development Core Team 2008).

RESULTS

We geocoded a total of 2,991 catch basins in 11 residential sites with lids allowing access to mosquitoes. The mean density of catch basins was 5.0 ± 0.68/ha and the density of catch basins containing immature mosquitoes was 1.9/ha. Trap efficiency in laboratory experiments showed that the closed cup recovered 37.7 ± 6.5% ($n = 5$) of the mosquitoes emerging under the trap and the open cup recovered 50.5 ± 3.8% ($n = 5$). Light trapping in the study region resulted in an average female *Culex* spp. per light trap per night of 5.6 ± 1.17 in 2009 and 7.7 ± 0.75 in 2010. In the paired field trials of the 2 traps made with different materials, the stainless steel mesh traps captured 18.3 ± 6.0 adult mosquitoes, while the black plastic traps captured 8.5 ± 4.9 ($t = 3.79$, df $= 7$, $P = 0.006$). All subsequent emergent trap data collected in 2009 and 2010 utilized the stainless steel trap type.

We deployed emergence traps in the field in 15 different catch basins for a total of 890 trap-hours in 2009 (Table 1). We captured a mean of 20.13 ± 9.05 male *Culex* spp. mosquitoes and 11.13 ± 5.08 female *Culex* in individual traps per trapping session, which ranged in duration from 43 to 117 h. In order to estimate total production, we first corrected the number of *Culex* in each collection cup (37.7% for closed cup and 50.5% for open cup). We then assumed homogeneous pupae distribution in the catch basin sump and estimated the number of *Culex* emerging outside the trap. The estimated mean number of female *Culex* spp. mosquitoes emerging from catch basins per day was 58.9 ± 30.8, while the estimated mean number of male *Culex* spp. mosquitoes was 86.2 ± 36.4. Given that the

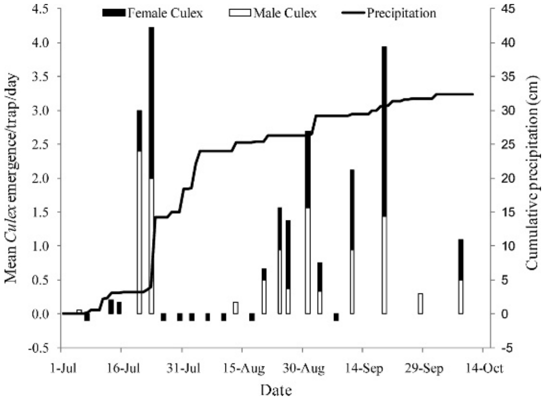

Fig. 2. Mean *Culex* spp. mosquitoes per emergence trap per day in suburban Chicago, IL, 2010. Cumulative precipitation measured at weather station 1.5 km from catch basins. Negative values represent days the emergence traps were checked but no adult mosquitoes were recovered.

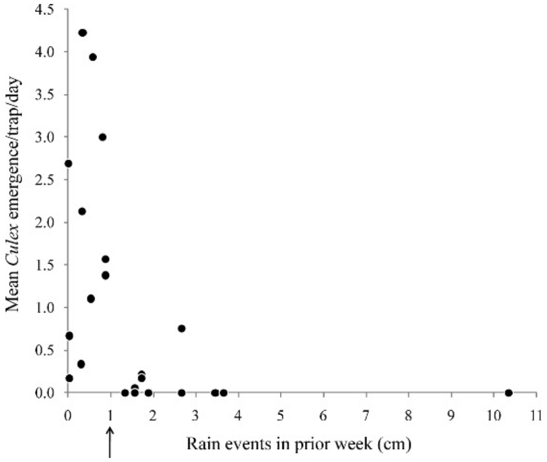

Fig. 3. Relationship between mean *Culex* mosquitoes per emergence trap per day and the largest cumulative precipitation event in a 24-h period in the prior week (cm). Arrow represents flushing threshold.

average catch basin surface area for the data collected in 2009 was 0.66 m^2, our estimates of the total number of *Culex* mosquitoes emerging per catch basin was 220.1 *Culex* mosquitoes/$m^2 \times day^{-1}$ (130.7 males and 89.4 females). With an estimate of 1.9 catch basins containing immature *Culex* mosquitoes per hectare, we extrapolated the total emergence of *Culex* mosquitoes from catch basins in our study area to be 274.2 *Culex* mosquitoes/ha $\times$ day^{-1} (111.4 $\pm$ 30.8 female *Culex* and 162.8 $\pm$ 36.4 male *Culex*).

In 2010, we deployed 4 emergence traps in 4 catch basins for 424 trap-days and calculated *Culex* mosquito emergence per trap per day as 0.45 $\pm$ 0.14 females and 0.47 $\pm$ 0.14 males (Fig. 2). Rain events $>$1 cm resulted in a flushing effect (Fig. 3). The primary outlier in Fig. 3 is a data point where the mean *Culex* emergence per trap per day was 0.75 $\pm$ 0.04 and the rain event in the prior week was 2.7 cm. The trap contents on this day were collected on September 3rd and the 2.7-cm rain came on September 2nd, and we noted that the adult mosquitoes were wet, which implies they emerged prior to the rain event.

DISCUSSION

Emergence traps have been used in previous studies to estimate total mosquito emergence from ephemeral wetlands (Smith and McIver 1984), swamps (Appleton and Sharp 1985), and ditches (Service 1977). Extrapolating emergence trap data can be problematic for several reasons (reviewed by Silver 2008, Walton 2009), including 1) pupal avoidance or attraction to the physical structure created by the trap, 2) effects of trap placement when mosquitoes are distributed heterogeneously, and 3) degradation of the catch in the collection cup due to exposure to elements or predators. In this study, we consider these artifacts and biases to be negligible for several reasons. First, our trap covered about one-third of the surface area of a typical catch basin (mean of 25.7% for 2009 data), which is a much higher proportion of total surface area than would be possible in studies of larger wetlands (e.g., 7% in Smith and McIver [1984] and 4–10% in Service [1977]). Second, our catch basins did not have emergent vegetation or other structures, other than the concrete edges, that would influence pupal distribution. Third, the few hours of midday sun exposure that some of the catch basins received through the grated lid would have had only minimal influence on pupal distribution during the peak hours of eclosion for *Cx. pipiens* at dawn and dusk (Karpova 2009). The influence of light and shadows, known to influence larval distributions (Clements 1999), would be further reduced given that the water levels in catch basins were about 1 m below the catch basin lid. Finally, we did not observe any other arthropods in the emergence traps or collection cups that could have fed on the adult mosquitoes, although chironomid midges and psychodid flies were present.

Our finding of significantly fewer *Culex* in the black plastic traps was perhaps due to the repulsive effect on pupae from shading of the opaque material (reviewed by Silver 2008), but the stainless steel mesh allowed better light penetration. The efficiency of the collection cup for recovering mosquitoes emerging inside the trap can also lead to biases; however, we estimated this efficiency in laboratory trials and used them as correction factors in our calculations of total abundance. We suspect the open cup design had better trap efficiency (proportion of adults reaching the cup) compared to the closed cup design because air flow allowed by the mesh screen encouraged upward movement into the cup. Given the high degree of uncertainty with our estimates of total *Culex* mosquitoes emerging from catch basins and because there are no previous studies to compare these measures to, future efforts to improve these estimates are warranted.

Many previous studies have estimated *Culex* production from pit latrines and septic tanks by collecting all mosquitoes emerging from the exit hole. Utilizing traps to collect all mosquitoes emerging from pit latrines in Tanzania, Curtis and Hawkins (1982) detected pits that produced >1,000 *Cx. quinquefasciatus* Say adults each night. A single highly productive septic tank (8.5 m × 2.75 m) in Burma produced 7,241 *Cx. pipiens fatigans* Wiedemann per day (or 309.7 individuals/$m^2 \times day^{-1}$) (De Meillon et al. 1967). The mean daily number of adult *Cx. quinquefasciatus* exiting septic tanks in 2 communities in southern Puerto Rico was 450 individuals/day (Mackay et al. 2009), and given the average size of the septic tanks of 7.7 m^2 (Mackay, personal communication) the estimated mean *Cx. quinquefasciatus* production from septic tanks was 58.5/day × m^{-2}. Our catch basin production estimates of 220.1 *Culex*/$m^2 \times day^{-1}$ is therefore within the range of previous studies of similar nutrient-rich environments. We note that our estimates of *Culex* emergence from catch basins only account for production from the sumps of the catch basins, which are designed to prevent debris (e.g., leaves and soil) from entering the network of underground pipes. In addition to these sumps, an extensive underground network of lateral pipes, manhole chambers, and main channels are also capable of holding water and provide additional larval habitat (Dhillon et al. 1985).

Our results also draw attention to the importance of "super-producer" catch basins, which yield disproportionate amounts of *Culex*, such as one in this study that produced an estimated 986 total (535 males and 451 females) *Culex* mosquitoes/day. During both years, the study region was under active mosquito abatement efforts led by local municipalities and mosquito abatement districts utilizing Altosid© (Wellmark International, Schaumburg, IL) XR-Briquets (30- or 150-day control; S-methoprene–based larvicide). Efficacy of S-methoprene tends to be lower in field trials compared to laboratory trials (Knepper et al. 1992, Butler et al. 2006), with a percent reduction of adult emergence ranging from about 62% to 97% reduction (Phillips et al. 1991, Knepper et al. 1992, Butler et al. 2006, Stockwell et al. 2006, Baker and Yan 2010). Efficacy of S-methoprene tends to be higher in catch basins with accumulated organic debris (Baker and Yan 2010), and the majority of the catch basins in this study had about 10–20 cm of sediment.

In summary, our study provides evidence that a new emergence trap was effective in measuring adult mosquito emergence in urban catch basins. We note that these traps stack easily for storage and that the removable collection cups with a removable screen lid are conveniently designed to aid in the processing of trapped mosquitoes. These traps should therefore aid in future research into urban mosquito ecology and abatement efforts.

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