Effect of Incandescent Light on Collection of West Nile Virus Vectors Using CDC Miniature Light Traps in Northern Colorado

Broox G. V. Boze,1,3,* Kelsey Renfro,1 Daniel Markowski,1 and Saul Lozano-Fuentes2,4

1Vector Disease Control International, 7000 N. Broadway, Suite 108, Denver, CO 80221, USA, 2Centers for Disease Control and Prevention, 3156 Rampart Road, Fort Collins, CO 80521, USA, and 3Corresponding author: tel: 956-459-1593, e-mail: bboze@vdci.net

Received 16 July 2021; Editorial decision 18 August 2021

Abstract

To evaluate whether the presence of clear incandescent light was attractive or refractive to host-seeking mosquitoes in northern Colorado, a Bayesian hierarchical model was created to measure differences in trap effectiveness based on presence or absence of phototactic cues. A total of eight CDC miniature light traps (with and without light) were set weekly across four locations in northern Colorado between Weeks 23 and 32 of year 2020. Culex mosquitoes (Diptera: Culicidae) accounted for 81% of all collections in this study with two vectors of West Nile virus being represented. The probability of catching both Culex tarsalis Coquillett and Culex pipiens Linnaeus was reduced when traps were equipped with light, but the difference was not statistically significant for Culex tarsalis. The clear reduction in the number of Culex pipiens caught when these traps were equipped with light indicates negative phototactic behavior and underestimation with current surveillance strategies. Removal of light from these traps may aid our understanding of these species’ distribution within the environment, improve collection efficiency, and help guide implementation of targeted control measures used in public health mosquito control.

Key words: Culex, mosquito, behavior, surveillance, West Nile virus

The concept of integrated mosquito management (IMM) was first described in 1871 and is composed of four major components: 1) surveillance, mapping, and a rational setting of action thresholds; 2) physical control through manipulation of habitat; 3) larval source reduction and adult control; and 4) monitoring for insecticide efficacy and resistance (American Mosquito Control Association (AMCA) 2017). Appropriately designed IMM programs rely heavily on surveillance data to guide management decisions and provide scientific evidence supporting targeted control strategies (Chevalier et al. 2004).

Most mosquito species are nocturnal or crepuscular in nature and exhibit minimal activity during daylight hours. Because of behavioral differences between species and the fact that mosquitoes, in general, are not equally distributed within an environment, sampling outdoor mosquito populations can be difficult, and the strategies utilized for attracting and tracking the populations continues to evolve and be a subject of study (Crans 1989). The standard adult mosquito surveillance tool for many years was the New Jersey light trap, developed in 1932 (Mulhern 1934). Because of its size and weight, it was replaced in many areas with the CDC Miniature Light Trap developed by Dan Sudia and Roy Chamberlain in the early 1960s at the Centers for Disease Control (CDC) Virus Vector Laboratory (VVL) in Montgomery, Alabama (Sudia and Chamberlin 1967, 1981). CDC light traps are traditionally powered by a 6-volt 12amp DC battery and utilize a small fan and air-actuated gate system to draw mosquitoes into a collection net. In addition, mosquito control districts typically add some form of attractant to increase trap productivity. Factors known to influence the efficacy of CDC light trap collections include use of CO2, trap placement, climatic conditions, and artificial light (Barr et al. 1963, Bidlingmayer 1967, Kline 2006).

Numerous studies have documented insect responsiveness to light patterns with many nocturnal groups exhibiting positive phototaxis (van Grunsven et al. 2014, Kim et al. 2019). As a result, standard mosquito surveillance tools, including the CDC light trap, utilize artificial light as an attractant (Bentley et al. 2009). Baik et al. (2020) have shown that day-biting Aedes aegypti (L.) are attracted to light during the day, but in some cases, light exposure inhibits flight activity of host-seeking mosquitoes (Sheppard et al. 2017). Light inhibits both host-seeking and biting behavior of malaria parasite vectors including Anopheles gambiae Giles (Das and Dimpoulos 2008) and Anopheles coluzzii Coetzee (Baik et al. 2020). Historical reports indicated that Culex larvae often exhibit positively phototactic behavior, but adults are variable in their behavior and tend to rest on dark objects rather than light ones (Holmes 1911). Increased awareness of differential behaviors to light across this medically important group of insects (family Culicidae) has led to optional photo...
switches on some trap designs. These modified trap designs support the importance of investigating local population dynamics, behavioral traits, species diversity, and the surveillance strategies used in making decisions about the use of public health pesticides.

Data collected from CDC light traps are used throughout Colorado, and many other regions, to guide targeted space sprays, which are noted by many mosquito control agencies as the only effective means for rapidly reducing transmission risk during arboviral disease outbreaks (AMCA 2017). In the absence of a human vaccine for West Nile virus (WNV), mosquito control and personal protection against mosquito bites are the only preventative measures available to reduce the risk of transmission (Winters et al. 2008). This study was designed to evaluate the effect of light on trapping prominent mosquito species in northern Colorado and guide public health surveillance efforts to use resources more efficiently.

Methods

To evaluate whether the presence of light was attractive or refractive to adult female mosquitoes, a total of eight CDC miniature light traps (Bioquip Part No. 2836BQ, Rancho Dominguez, CA) were baited with CO₂ (2 pounds of pelletozed dry ice) and set weekly between Weeks 23 and 32 for a total of 80 trap nights, within a centralized (5 m²) area of Denver. Four trap locations were identified for use in this study based on proximity to known aquatic habitats utilized for oviposition and larval growth of Culex species. Two identical traps (one with Bioquip 4W CM47 light, and one without light) were placed approximately 6 feet above ground. All trap locations had similar vegetation and climate. The sites consisted of predominantly deciduous hardwood vegetation that included Plains Cottonwood (Populus deltoids), Quaking Aspen (Populus tremuloides), Gambel Oak (Quercus gambelii), Chokecherry (Prunus virginiana), and Boxelder (Acer negundo). At each location, the traps were set approximately 20 m apart, a distance previously shown to not result in trap interference. Traps were set weekly at each location between 15:00 and 17:00, and then picked up the following morning between 07:00 and 09:00. Weekly trap collections were maintained on dry ice and transported to a centralized laboratory where they were sorted and identified to species utilizing physical characteristics and dichotomous keys (Darsie and Ward 2005).

To assess differences in trap design, it was assumed that the size of the mosquito population was the same over time at the different collection sites. To standardize the data for changes in climatic conditions (average daily temperature of 75.06°F, average humidity 39.39%), abundance data were pooled into 5, 2-week periods for a total of five sampling events between Weeks 23 and 32. With this study design, differences between groups should result from having (or not having) a light source installed in the traps. Algebraically, the following describes the approach.

\[
N_i \sim \text{Poisson}(\lambda_i)
\]

\[
\text{Count}_{ij} \sim \text{Binomial}(p_{ij}, N_i)
\]

\[
\text{logit}(p_{ij}) = \beta_0 + \beta_1 \cdot \text{light}_i
\]

N is a latent variable describing the number of mosquitoes in each i trapping location. It was assumed that the number of mosquitoes resulted from a Poisson process with a mean number of mosquitoes, λ, in each sampling occasion k. The Count of mosquitoes caught in the traps in each repeated measurement (j) was assumed to follow a binomial distribution, with \( p_{ij} \) representing the probability of catching a female mosquito; \( p_{ij} \) can be considered the trapping efficacy, which is the variable of interest. Trapping efficacy \( (p_{ij}) \) was described using a linear model with the slope driven by the presence of light in the traps (‘yes’/’no’). The overall model was evaluated using a Bayesian hierarchical model and solved using JAGS.

Results

A total of 2,320 female mosquitoes representing nine species were collected during this study (Table 1). The primary species collected include Culex pipiens and Culex tarsalis, in addition to the floodwater species Aedes vexans Meigen. These species accounted for 98% of the collection with Cx. pipiens accounting for 56.5% (\( n = 1,313 \)) of the sample, Cx. tarsalis accounting for 24.5% (\( n = 570 \)) of the sample, and Ae. vexans accounting for 17% (\( n = 395 \)) of the sample. Other mosquito species collected included Aedes dorsalis Meigen (\( n = 3 \)), Aedes melanomn Dyar (\( n = 1 \)), Aedes nigromaculis Ludlow (\( n = 2 \)), Aedes trivittatus Coquillett (\( n = 4 \)), Anopheles freeborni Aitken (\( n = 1 \)), and Culiseta inornata Williston (\( n = 3 \)). Given the low abundance of these six species in our collections, these data were omitted from this analysis.

Mean Number of Mosquitoes per Collection (\( \lambda \))

The mean number of mosquitoes in the population increased from June to August for Culex species but not Ae. vexans (Table 1).

The Effect of Light (\( \beta_1 \))

The slope (i.e., \( \beta_1 \)) for Cx. pipiens and Cx. tarsalis regressions were \(-2.31 [-2.53, -2.10] \) and \(-1.04 [-1.28, 0.82] \), respectively; these slopes were statistically different from zero demonstrating that the presence (or absence) of the light did have a significant effect on trapping efficacy. This was not the case for Ae. vexans (\( \beta_1 = 0.07 [-0.29, 0.45] \)); however, the number of individuals collected for this species was significantly lower compared to the Culex species.

Trapping Efficacy (\( p \))

The probability of catching a mosquito (i.e., \( p \)) as a function of light is presented in Fig. 1. The presence of a light reduced \( p \) in both Culex spp., but not in Ae. vexans. However, the difference is not statistically significant in Cx. tarsalis since the credibility intervals overlap between treatments.

Discussion

Given the importance of detecting mosquito-borne viruses early in public health driven programs (Nasci et al. 2002, Jones et al. 2011,
Similarly, was a clear reduction in the number of *Cx. pipiens* species. From the samples collected in northern Colorado, there is a source as it can affect the sampling of medically important mosquito species. With approximately 250 mosquito species in North America (*Darsie and Ward 2005, Shahhosseini et al. 2020*), the species of concern in any given geography can be considerably diverse and a variety of trapping strategies may be used (*Silver 2007*). Just as mosquito populations can have localized feeding preferences and a variety of trapping strategies may be used (*Silver 2007*), local mosquito populations may also have adaptations for different attractants that allow for varying levels of trap efficiency.

Although the standard CDC miniature light trap is traditionally used with a small light source, many mosquito surveillance programs modify their traps for use without light. The data presented here support the rationale that not all surveillance traps should use a light source, as observed with *Aedes* species. As mosquito populations can have localized feeding preferences (*Temperle et al. 1965, Apperson et al. 2002, Hamer et al. 2009*), they can exhibit localized behavioral differences (*Ruiz-López 2020*). Consequently, local mosquito populations may also have adaptations for different attractants that allow for varying levels of trap efficiency.

![Fig. 1. Probability of catching mosquitoes based on species and presence/absence of incandescent light in CDC miniature light trap.](https://academic.oup.com/jinsectscience/article/21/5/10/6380834)

Schwab et al. (2018) and the costs associated with maintaining effective surveillance programs (*Wright et al. 2001, Healy et al. 2015*), it is imperative that mosquito trapping programs operate as efficiently as possible. A fundamental aspect of that efficiency is to collect as many target mosquito species as possible with each sampling event. While some programs may focus on the primary vectors of West Nile (*Culex spp.*), others may be concerned primarily with *Aedes* species. With approximately 250 mosquito species in North America (*Darsie and Ward 2005, Shahhosseini et al. 2020*), the species of concern in any given geography can be considerably diverse and a variety of trapping strategies may be used (*Silver 2007*). Just as mosquito populations can have localized feeding preferences (*Temperle et al. 1965, Apperson et al. 2002, Hamer et al. 2009*), they can exhibit localized behavioral differences (*Ruiz-López 2020*). Consequently, local mosquito populations may also have adaptations for different attractants that allow for varying levels of trap efficiency.

Although the standard CDC miniature light trap is traditionally used with a small light source, many mosquito surveillance programs modify their traps for use without light. The data presented here support the rationale that not all surveillance traps should use a light source, as it can affect the sampling of medically important mosquito species. From the samples collected in northern Colorado, there was a clear reduction in the number of *Cx. pipiens* collected when the CDC light traps were equipped with a clear incandescent light. Similarly, *Culex quinquefasciatus* Say have demonstrated a preference for CDC traps without a light source in Tanzania (*Mborea et al. 2000*). While the reduction in *Cx. tarsalis* was not statistically significant between traps with and without a light, it is postulated that a larger sample size or longer period of collection could potentially elucidate a negative phototactic preference in this species as well.

For the other principal species collected in this study, *Ae. vexans*, the use of a light had no significant effect on collection efficacy. Therefore, it is suggested that surveillance programs having a small light source attached to the trap would not attract any more *Ae. vexans* but could decrease the collection of other medically important species in the area. This study did not attempt to measure the amount of artificial light at or near trap sites. There was certainly both astronomical and ecological light pollution throughout the course of the study that could have impacted the collections as many insect species are impacted by artificial light sources (*Owens and Lewis 2018*). Furthermore, it is well known that mosquitoes are attracted to different wavelengths of light, as well as the intensity of light (*Burkett et al. 1998, Burkett and Butler 2005, peach et al. 2019*), although neither of these parameters were measured.

These data support the idea that there is no single approach to the surveillance of mosquito species and behavioral traits of local species should be taken into consideration when establishing baseline data for IMM. Light traps serve a critical role in mosquito surveillance for a variety of species (*AMCA 2017*) but additional tools, or slight modifications of these tools, may be necessary in some areas based on the habitat, species diversity, or local behavioral traits. Further research is needed to replicate these results in other geographic locations and determine more precisely the parameters affecting the ability of light to increase or decrease trapping efficacy.

### Acknowledgments
The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the Centers for Disease Control and Prevention (CDC).

### References Cited

American Mosquito Control Association (AMCA). 2017. Best practices for integrated mosquito management: a focused update. AMCA, Sacramento, CA.

Apperson, C. S., B. A. Harrison, T. R. Unnasch, H. K. Hassan, W. S. Irby, H. M. Savage, S. E. Aspen, D. W. Watson, L. M. Rueda, B. R. Engber, et al. 2002. Host-feeding habits of *Culex* and other mosquitoes (Diptera: Culicidae) in the Borough of Queens in New York City, with characters and techniques for identification of *Culex* mosquitoes. J. Med. Entomol. 39: 777–785.

Baik, L. S., C. Nave, D. D. Au, T. Guda, J. A. Chevez, A. Ray, and T. C. Holmes. 2020. Circadian regulation of light-evoked attraction and avoidance behaviors in daytime- versus nighttime-biting mosquitoes. Curr. Biol. 30: 3252–3259.e3.

Barr, A. R., A. T. Smith, M. M. Boreham, and K. E. White. 1963. Evaluation of some factors affecting efficiency of light traps in collecting mosquitoes. J. Econ. Entomol. 56: 123–127.

Bentley, M. T., P. E. Kaufman, D. L. Kline, and J. A. Hogsett. 2009. Response of adult mosquitoes to light-emitting diodes placed in resting boxes and in the field. Publications from USDA-ARS/UNL Faculty. 997.

Biglina Mayer, W. L. 1967. A comparison of trapping methods for adult mosquitoes: species response and environmental influence. J. Med. Entomol. 4: 200–220.

Burkett, D. A., and J. F. Butler. 2005. Laboratory evaluation of colored light as an attractant for female *Aedes aegypti, Aedes albopictus, Anopheles quadrimaculatus,* and *Culex nigripalpus.* Fla. Entomol. 88: 383–389.

Burkett, D. A., J. F. Butler, and D. L. Kline. 1998. Field evaluation of colored light-emitting attractants for woodland mosquitoes and other diptera in north central Florida. J. Am. Mosq. Control Assoc. 14: 186–193.

Chevalier, V., S. de la Rocque, T. Baldet, L. Vial, and F. Roger. 2004. Epidemiological processes involved in the emergence of vector-borne diseases: West Nile fever, Rift Valley fever, Japanese encephalitis and Crimean-Congo hemorrhagic fever. Rev. Sci. Tech. OIE 23: 535–555.

Cranes, W. J. 1989. Resting boxes as mosquito surveillance tools, pp. 53–57. In Proceedings of the Eighty-Second Annual Meeting of the New Jersey Mosquito Control Association, 15–17 March 1989, Ashbury Park, NJ.

Darsie, R. F., and R. A. Ward. 2005. Identification and geographical distribution of the mosquitoes of North America, North of Mexico. University Press of Florida, Gainesville, FL.

Das, S., and G. Dimopoulos. 2008. Molecular analysis of photic inhibition of blood-feeding in *Anopheles gambiae*. BMC Physiol. 8: 23.

Hamer, G. L., U. D. Kitron, T. L. Goldberg, J. D. Brawn, S. R. Loss, M. O. Ruiz, D. B. Hayes, and E. D. Walker. 2009. Host selection by *Culex*
*Culex pipiens* mosquitoes and West Nile virus amplification. Am. J. Trop. Med. Hyg. 80: 268–278.

Healy, J. M., W. K. Reisen, V. L. Kramer, M. Fischer, N. P. Lindsey, R. S. Nasci, P. A. Mucedo, G. White, R. Takahashi, L. Khang, et al. 2015. Comparison of the efficiency and cost of West Nile virus surveillance methods in California. Vector Borne Zoonotic Dis. 15: 147–153.

Holmes, S. J. 1911. The reactions of mosquitoes to light in different periods of their life history. Anim. Behav. 1: 29–32.

Jones, R. C., K. N. Weaver, S. Smith, C. Blanco, C. Flores, K. Gibbs, D. Markowski, and J. P. Mutebi. 2011. Use of the vector index and geographic information system to prospectively inform West Nile virus interventions. J. Am. Mosq. Control Assoc. 27: 315–319.

Kim, K. N., Q. Y. Huang, and C. L. Lei. 2019. Advances in insect phototaxis and application to pest management: a review. Pest Manag. Sci. 75: 3135–3143.

Kline, D. L. 2006. Traps and trapping techniques for adult mosquito control. J. Am. Mosq. Control Assoc. 22: 490–496.

Mboera, L., B. G. J. Knols, M. Braks, and W. Takken. 2000. Comparison of carbon dioxide-baited trapping systems for sampling outdoor mosquito populations in Tanzania. Med. Vet. Entomol. 14: 257–263.

Mulhern, T. D. 1934. A new development in mosquito traps, pp. 137–140. In Proceedings of the 21st New Jersey Mosquito Extermination Association, 7–9 March 1934, Lindenwold, NJ. Accessed online at http://www.njmca.org/Proceedings/1934%20Proceedings.pdf

Nasci, R. S., N. Komar, A. A. Marfin, G. V. Ludwig, L. D. Kramer, T. J. Daniels, R. C. Falco, S. R. Campbell, K. Brooks, K. L. Gottfried, et al. 2002. Detection of West Nile virus-infected mosquitoes and seropositive juvenile birds in the vicinity of virus-positive dead birds. Am. J. Trop. Med. Hyg. 67: 492–496.

Owens, A. C. S., and S. M. Lewis. 2018. The impact of artificial light at night on nocturnal insects: a review and synthesis. Ecol. Evol. 8: 11337–11358.

Peach, D. A. H., E. Ko, A. J. Blake, and G. Gries. 2019. Ultraviolet inflorescence cues enhance attractiveness of inflorescence odour to *Culex pipiens* mosquitoes. PLoS One 14: e0217484.

Ruiz-López, M. J. 2020. Mosquito behavior and vertebrate microbiota interaction: implications for pathogen transmission. Front. Microbiol. 11: 573371.

Schwab, S. R., C. M. Stone, D. M. Fonseca, and N. H. Fefferman. 2018. The importance of being urgent: the impact of surveillance target and scale on mosquito-borne disease control. Epidemics 23: 55–63.

Shahhosseini, N., G. Wong, C. Frederick, and G. P. Kobinger. 2020. Mosquito species composition and abundance in Quebec, Eastern Canada. J. Med. Entomol. 57: 1025–1031.

Sheppard, A. D., S. S. C. Rund, G. F. George, E. Clark, D. J. Acri, and G. E. Duffield. 2017. Light manipulation of mosquito behaviour: acute and sustained photic suppression of biting activity in the *Anopheles gambiae* malaria mosquito. Parasit. Vectors 10: 255.

Silver, J. B. 2007. Mosquito ecology: field sampling methods, 3rd ed. Springer Science & Business Media, New York.

Sudia, W. D., and R. W. Chamberlain. 1967. Collection and processing of medically important arthropods for arbovirus isolation. Communicable Disease Center, Atlanta, GA.

Sudia, W. D., and R. W. Chamberlin. 1981. Battery-operated light trap, an improved model. Centers for Disease Control, U.S. Public Health Service, Department of Health and Human Services, Atlanta, GA.

Tempelis, C. H., W. C. Reeves, R. E. Bellamy, and M. F. Lofy. 1965. A three-year study of the feeding habits of *Culex tarsalis* in Kern County, California. Am. J. Trop. Med. Hyg. 14: 170–177.

van Grunsven, R. H. A., M. Donners, K. Boekh, I. Tichelarr, K. G. van Gellef, D. Groenendjak, F. Berendse, and E. M. Veenendall. 2014. Spectral composition of light sources and insect phototaxis, with an evaluation of existing spectral response models. J. Insect Conserv. 18: 225–231.

Winters, A. M., R. J. Eisen, S. Lozano-Fuentes, C. G. Moore, W. J. Pape, and L. Eisen. 2008. Predictive spatial models for risk of West Nile virus exposure in eastern and western Colorado. Am. J. Trop. Med. Hyg. 79: 581–590.

Wright, S. A., B. E. Eldridge, and D. A. Brown. 2001. Cost effectiveness of three arbovirus surveillance methods in northern California. J. Am. Mosq. Control Assoc. 17: 118–123.