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Short Communication

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Short Communication

Blinded by the light: does heat or light enhance wild mosquito (Diptera: Culicidae) attraction to CO_2-baited traps in the Great Salt Lake area?

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The New Jersey Light Trap has been among the earliest trap models used for mosquito surveillance in the United States. This trap was modernized in the 1950s to the miniature CDC light trap, with the addition of CO_2 following soon after. The incandescent light has the tendency to attract nontarget insects, as well as losing a substantial portion of their energy as heat. Few studies have delineated whether heat or light in isolation make a difference in field collections using the former traps within the United States. Our study focused on isolating heat and light variables by using incandescent bulbs, light emitting diode (LED) bulbs, and electric heating patches affixed to a base model CO_2 trap as designed at the Salt Lake City Mosquito Abatement District. Sites were selected in the urban and suburban foothills and canyons of the Wasatch Mountain front, industrial areas near the Salt Lake City International Airport, and rural wetlands in the marshes outlying the Great Salt Lake. Five traps were replicated within each sector during the summer and fall summer seasons. Collections were composed of *Aedes dorsalis* (Meigen), *Culex pipiens* L., *Culex tarsalis* Coquillett, and *Culiseta inornata* (Williston). Composition changes were a result of seasonal, rather than spatial, shifts. The results showed that LED light traps depressed collections of key species. Otherwise, there were negligible differences in collections among incandescent, heat film, and base model traps. In the Intermountain West, the miniature CDC trap is reliable enough to make programmatic decisions even if light usage varies by district.

Key words: urban, rural, *Aedes*, *Culex*, host-seeking

Introduction

The development of the United States Centers for Disease Control and Prevention (CDC) miniature light trap by Sudia and Chamberlain (1962) in the 1960s replaced its predecessor, the New Jersey Light Trap (NJLT) developed in 1932 (Mulhern 1942). It was shortly thereafter adopted as a "gold standard" for mosquito surveillance programs across the United States because of its lightweight configuration and simple design, which made it practical for arboviral surveillance in various locations (McNelly 1989). In 1980, an additive lure component, CO_2 in the form of dry ice, notably improved trap performance, with a 400–500% increase in mosquito catch numbers (Newhouse et al. 1966). With the addition of CO_2, particularly in absence of an onboard light, the CDC trap utility was improved for vector species with less bycatch of nontarget insects (Reisen et al. 1983, 2000, McNelly 1989).

In the research conducted by Magnarelli (1975) in New York, various permanent water and opportunistic species were reliably collected using the CO_2 addition, including *Anopheles quadrimaculatus* Say, *Anopheles walkeri* Theobald, *Coquillettidia perturbans* (Walker), *Culex restuans* Theobald, and *Culiseta morsitans* (Theobald), amidst trap totals in excess of 5,000 mosquitoes over 17 wk. Furthermore, in a study conducted by Feldlaufer and Crans (1979), 14 species from 6 genera were collected from various floodwater and saltmarsh environments. The most abundant species included *Aedes canadensis* (Theobald), *Aedes cantator* (Coquillett), *Aedes vexans* (Meigen), and *Aedes solicitans* (Walker), and *Culex salinarius* Coquillett, which represented 98% of the 15,000 mosquitoes collected in the study. In the western United States, where diversity gives way to explosive abundance of 1 or 2 species, *Culex tarsalis* Coquillett was collected more abundantly with CO_2 as the only attractant (Reisen et

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al. 1983), especially if there was no rain pan over the fan (Reisen et al. 2000). Since then, few alterations to the trap have been made after the ground-breaking addition of CO_2. However, from time to time, some additions or eliminations to the trap were made for practicality, which mainly pertain to battery selection and collection devices (Sudia and Chamberlin 1962, McNelly 1989, Spitzen et al. 2008).

Though, it has been noted that a 25-watt incandescent bulb was originally a prominent feature of the original NJLT, and was ported to the standard CDC trap as a CM47 0.95-watt bulb to retain the lure but with less power requirements. However, the light itself has since been subject to persistent controversy (Boze et al. 2021). For example, in Tanzania by Mboera et al. (2000) reported that the incandescent lure reduced the capture of *Culex quinquefasciatus* Say by 50% when added to a CDC trap baited with CO_2. Additionally, a significant number of other nontarget insects were also caught by this trap configuration, the most prominent of which were nocturnally active Lepidoptera. To improve the mosquito outcomes with light, primitive light emitting diodes (LEDs) were investigated by Burkett et al. (1998) in comparison to the standard incandescent bulb. However, the broad-spectrum incandescent bulb was more effective than LEDs for a variety of woodland pool mosquito species (Burkett et al. 1998), such as *Aedes atlanticus* Dyar & Knab, *Anopheles crucians* Wiedemann, *Culex nigripalpus* Theobald, Culiseta *melanura* (Coquillett), and *Uranotaenia sapphirina* (Osten Sacken), duplicating previous findings by Mann (1993).

Visual cues from light were considered essential for effective surveillance traps (Cohnstaedt et al. 2008), and it was believed that modern LED technology could deliver upgrades over the previous iterations of both primitive LEDs and incandescent bulbs. Despite the selective merits of an incandescent bulb, Cohnstaedt et al. (2008) and Costa-Neta et al. (2017) emphasized LED technology for the energy efficiency, affordability, durability, long life, and control of light wavelengths. Mosquitoes have generally appeared to prefer shorter wavelengths of light at 570 nm or less (Burkett et al. 1998, Silva et al. 2015a, 2015b, 2016). Additionally, Costa-Neta et al. (2017) reported that green LEDs were more attractive than blue LEDs and unmodified incandescent bulbs. The green LED trap accounted for 43.3% of the overall catch, composed primarily of semi-permanent floodplain species such as *Anopheles argyritarsis* Robineau-Desvoidy, *Anopheles darlingi* Root, *Anopheles evansae* (Brèthes), *Anopheles galvaoi* Causey, Deane & Deane, *Anopheles goeldii* Rozeboom & Gabaldón, and *Anopheles triannulatus* (Neiva & Pinto). In comparison with the blue LED trap (31.8%), green LED traps yielded a 11.5% increase over blue and 18.4% increase over the incandescent control trap (24.9%). In spite of some appealing success with *Anopheles* mosquitoes, data in the intermountain and western United States tended to conclude that light-baited traps do not particularly outperform their unlit counterparts for key vector species (Reisen et al. 1983, Boze et al. 2021).

Over emphasis on the value of the light lure (Cohnstaedt et al. 2008, Jhaiaun et al. 2021) could have distracted from possible confounding variables. Light spectra notwithstanding, a detail that has received less attention is the light source's heat signature. In historical trapping technology, such as the NJLT and early iterations of the CDC miniature light trap, incandescent bulbs were the only light option available (Cohnstaedt et al. 2008). Incidentally, the efficiency for incandescent bulbs to convert electrical current to light is only about 6%, with the remaining 94% emitted in the form of heat or infrared radiation (Cohnstaedt et al. 2008). Heat emission is also important because mosquitoes rely on their ability to sense differences between environmental temperatures and host temperatures to find their hosts (Corfas and Vosshall 2015, Zermoglio et al. 2017, Carnaghi et al. 2021, Reinhold et al. 2022). Despite this, research focused on thermal signatures has been minimal (Reinhold et al. 2022). Furthermore, contemporary surveillance programs have, in many cases, discarded their light traps in favor of CO_2-baited traps (Boze et al. 2021). But it is possible that ambiguous light trap results in past studies have been due, in part, to the lack of heat emission as an independent variable. To help investigate this, we conducted field comparisons using CO_2 alone with no heat or light, incandescent light, LED light and heat alone to augment CO_2 across an urban-to-rural gradient in the Greater Salt Lake area of Utah. Our primary aim was to provide additional guidelines for mosquito control programs which may have limited access to CO_2 or modern traps and evaluate the ongoing utility of the standard NJLT/CDC miniature traps.

Materials and Methods

The Salt Lake City Mosquito Abatement District (SLCMAD) has previously created the SLC trap (Fig. 1A), a 3D-printable trap base model that does not use a light (Bibbs et al. 2024). As part of a previous study, has evaluated mechanical aspects, such as fan specifications, CO_2, battery configuration, and ease of assembly. Part of the reason for eliminating the light was to reduce the catch of nontarget insects as well as the number of parts needed to construct an affordable and working CDC trap equivalent, while also considering arguments surrounding whether light contributes to the trap performance or hinders it. Modifications were made to the base design to ensure heat could be isolated from light as an attractant variable.

The heat trap was assembled on the same design as Bibbs et al. (2024) with the addition of a 15 × 10 cm (6 × 4 in) heat film (Fig. 1B; B0727X2DGC, 5-volt, IcStation KaiJun Xu, Wuhan, CHN) that reached 135 ± 3 °C (275 ± 5 °F). For traps using a light, a 3D-printable ballast was affixed to the trap body and seated with a light socket (Fig. 1C and D; 1156 Taillight socket, Dragonmarts Co. Ltd., Hong Kong, China). A combination heat and LED trap was used as a corollary to the incandescent light trap (Fig. 1D). Heat film and bulb temperatures were verified with temperature probes and secondarily validated with an infrared laser thermometer. Traps with full-spectrum, 402 lumen, 6000 K white incandescent bulbs (Fig. 1E; 1156LL 10 watt/12-volt, Part#SG_B00B2B37N8_US, Osram Licht AG, Munich, Germany) reached a similar temperature as the heat films at 135 ± 3 °C (275 ± 5 °F). Traps using 9-panel, full-spectrum, 450 lumen, 6000 K white LED bulbs (Fig. 1C and D; 1156 BA15S 12-volt, Part#FH1156-5050-9 6-30V-W*2, Ruiandsion, Guangzhou, China) were notably cooler at an operating temperature of 24 ± 5 °C (75 ± 10 °F). All trap components were powered by 6-volt sealed lead-acid batteries (PS-6100 6v 12Ah, Power Sonic Co., San Diego, CA, USA).

For general testing, traps were placed on poles positioned at least 50 m apart from the nearest trap. The poles were slotted over rebar hammered into the ground and stood approximately 1.8 m (6 ft) high. Traps were attached to each pole along with a collection net and were operated for 24 h per trap night. Each trap was baited with 300 ml/min of CO_2 released from a pressure regulated cylinder, which was kept in a transport container resting with the trap pole (Bibbs et al. 2024). Trap attractants were replicated for 5 nights each across 3 habitat types (Fig. 1F): (i) Urban: Utah's Hogle Zoo, which is itself a vegetated suburban/urban habitat within the primary residential foothills and canyons of the Wasatch Mountains; (ii) Industrial: SLCMAD property near the International Airport;

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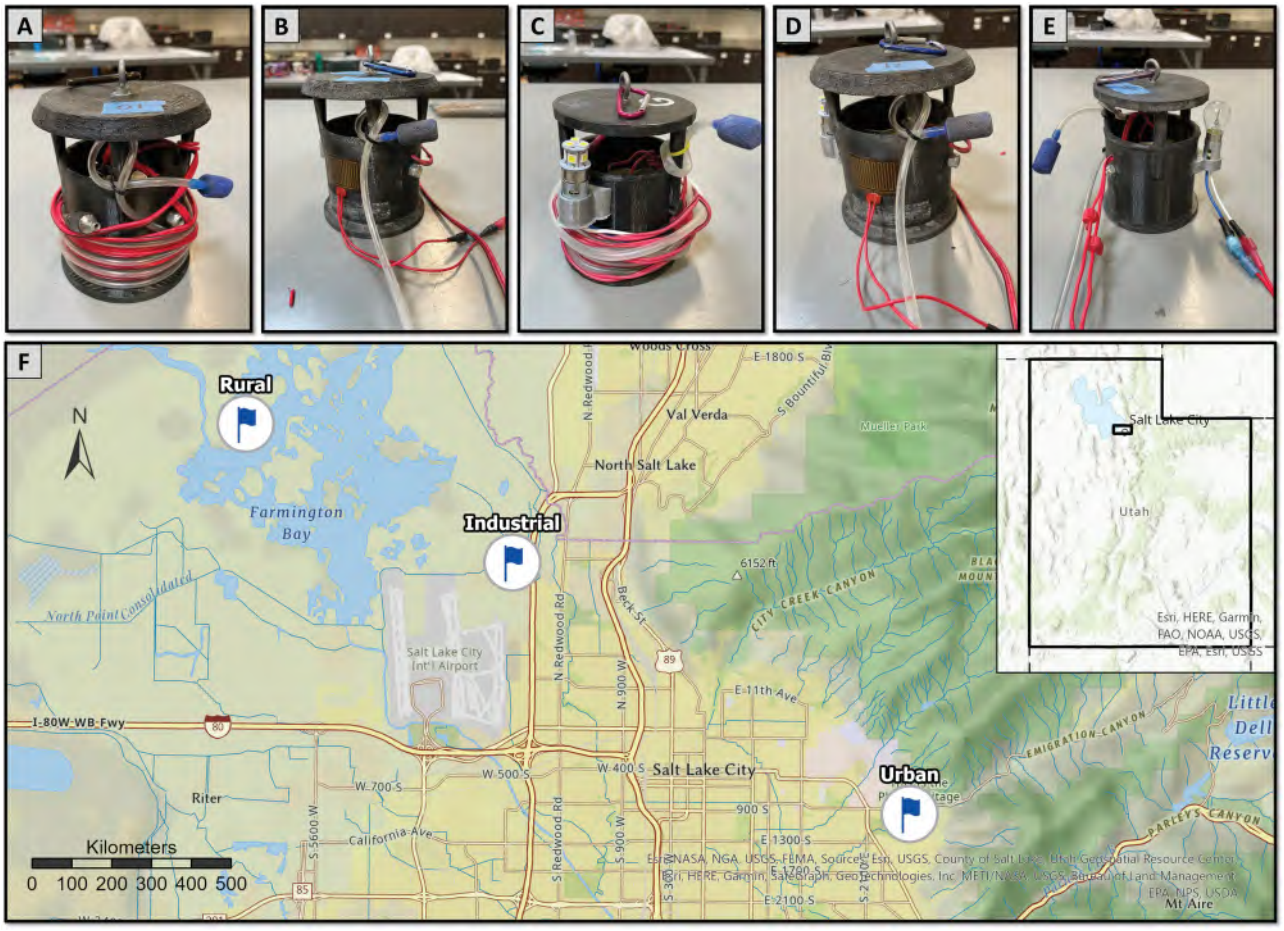


Fig. 1. Site and trap allocations for study. Trap types for comparison were all CO_2 baited, and included A) a basic CO_2 trap with no light; B) a trap with a 135 °C heat film; C) a trap with a 120 volt equivalent LED light; D) a trap with both an LED bulb and heat film; E) a trap with a 120 volt incandescent bulb that warmed to 135 °C; and F) study locations spanned an urban-to-rural gradient across the Greater Salt Lake area.

and (iii) Rural: the semi-permanent wetlands surrounding the Great Salt Lake. Traps were evaluated during the summer and repeated during the fall season. Total trapping effort was 30 trap nights (5 per habitat, per season).

Collected mosquitoes were killed at −80 °C before trap contents were counted with a hybrid camera and microscopy set-up using ImageJ (Kesavaraju and Dickson 2012) and using identified reference key materials (Darsie and Ward 2016). Data were analyzed using R statistical software (v.4.2.1, The R Foundation for Statistical Computing, Vienna, Austria) via RStudio (v. 3.3.0, RStudio PBC, Boston, MA, USA). Lure types at each of the 3 test regions (urban, industrial, rural) were analyzed using a Generalized Linear Mixed Model and Poisson distribution for collection numbers for each mosquito species. The Shannon–Weiner richness index and the Pielou evenness index were calculated for each trap type by region. Analyses were conducted separately for summer and fall collection data. Data summarized graphically within Fig. 2 have been appended in tabular form within Supplemental Table S1.

Results

In the urban field sites during summer, only *Cx. pipiens* collections were significantly reduced in LED light traps ($Z_{4,16} = -2.05$, $P = 0.04$). In the industrial and rural field sites during summer, replication among trap types did not result in significant differences in collection yield for any species among the trap models (Fig. 2A–C). In the fall, *Aedes dorsalis* comprised a greater portion of the collection, with fewer *Cx. tarsalis* present than in the peak of summer (Fig. 2D–F). Fall trapping with LED light traps yielded significantly fewer *Ae. dorsalis* ($Z_{4,16} = -2.59$, $P = 0.01$), while incandescent bulbs collected significantly more *Cx. pipiens* ($Z_{4,16} = -2.15$, $P = 0.03$) at the urban sites. In contrast, using the LED light trap at the industrial site in fall yielded fewer *Ae. dorsalis* ($Z_{4,16} = -2.56$, $P = 0.01$) and *Cx. pipiens* ($Z_{4,16} = -2.58$, $P = 0.01$). At the rural site, fall trapping with the LED light trap reduced *Ae. dorsalis* ($Z_{4,16} = -1.88$, $P = 0.05$) and *Cx. tarsalis* ($Z_{4,16} = -1.81$, $P = 0.05$); while there was elevated collection of *Cx. tarsalis* in both the incandescent ($Z_{4,16} = 2.35$, $P = 0.02$) and LED + heat film traps ($Z_{4,16} = 1.812$, $P = 0.05$).

Species richness and evenness was similar among trap types, but with decreasing diversity towards the city center (urban < industrial < rural). One exception arose with the LED trap at the rural sites in fall, which were monotypic for *Ae. dorsalis* (Fig. 2). Aside from the aforementioned outlier, the overall diversity did not decline in fall versus the summer across the various trap models, even if the proportional abundance did change. Although richness and evenness were less than half of the summer values in both the industrial and rural sites, this was observed in the outcomes from all trap models. In this specific study in the given year that it was conducted, there was no meaningful bycatch nor male mosquito collections in either of our summer or fall trials.

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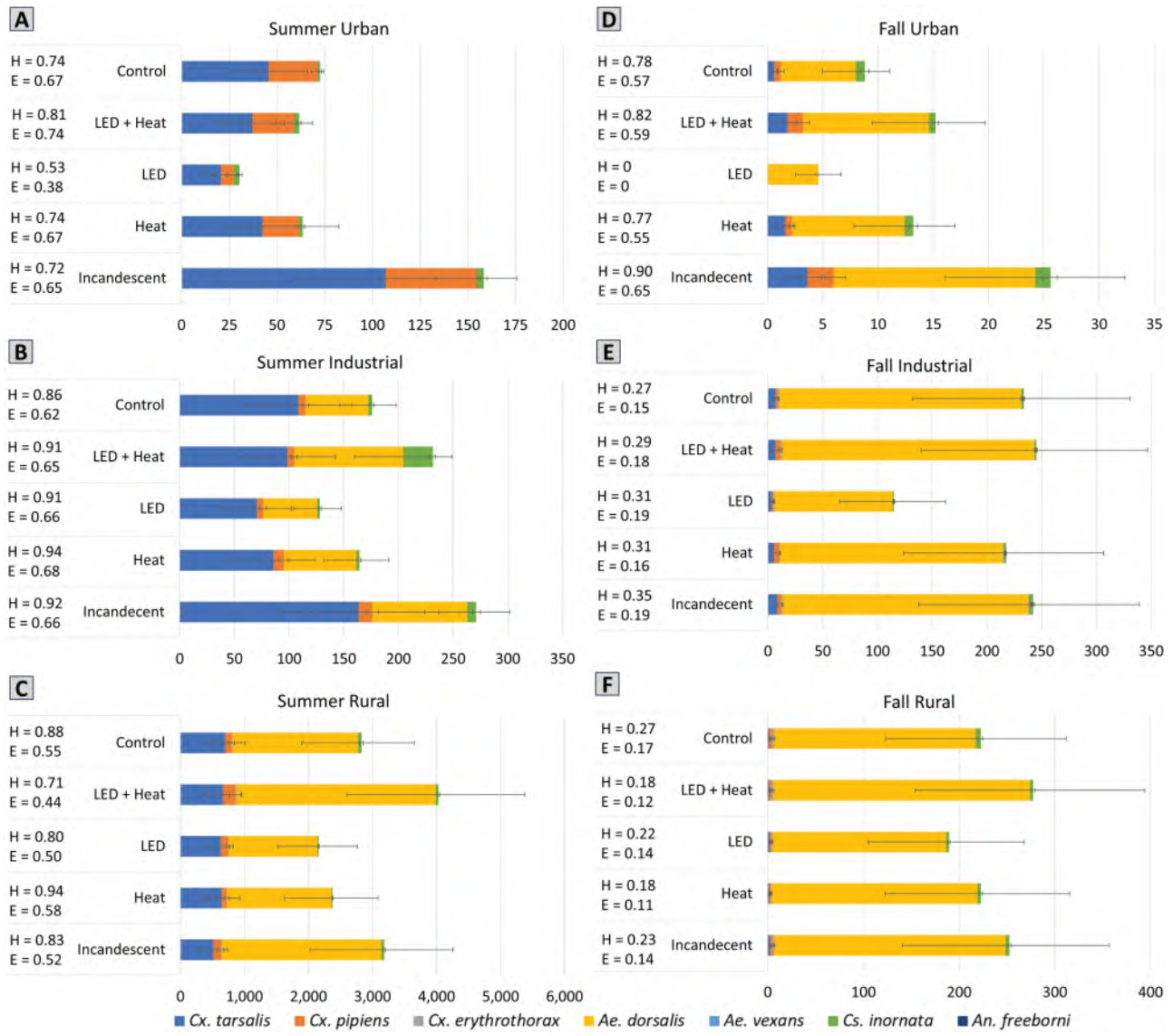


Fig. 2. Stacked bar graphs with mean counts of females per trap night of species collected (x-axis) during 5 replicates of Latin squares trapping. Trapping was conducted for 24 h per trap night during the summer (A–C) and again in fall (D–F) for urban (A, D), industrial (B, E), and rural (C, F) areas within Salt Lake City. Traps ranged from basic CO_2 traps (Control), CO_2 traps with heat (Heat), CO_2 traps with light (LED), and CO_2 traps possessing both heat and light (LED + heat and incandescent). Graphs are shown with standard error of the mean as I-bars and Shannon–Weiner index (H) with Peilous evenness index (E) annotated left of the axis.

Discussion

Overall, the LED light, when not accompanied by additional heat, tended to depress the collections of *Ae. dorsalis* and *Culex* sp. vectors. We did not find any significant changes in diversity within mosquito collections as a direct result of differentially including heat, light, both, or neither across an urban-to-rural gradient in Utah's Central Valley. Weather tends to confound field studies with traps, and the tendency in Utah's Central Valley is for intermittent periods of unpredictable heavy winds and rainfall, primarily due to effects from the Great Salt Lake and proximity to major mountain chains. Because many types of mosquitoes are weak fliers in rainy and windy conditions (Karki et al. 2016), collection numbers may not have been optimized during unsuitable weather. A more in-depth study may be able to parse out the differences from seasonal and competing stimuli during a longitudinal study emphasizing trap lures.

Our goals herein were principally for operational decision making. The data from this study were intended to enhance accuracy with replication in different seasons and across a clear urban-rural gradient. For the purposes of SLCMAD, the collections of key species in the area—*Ae. dorsalis*, *Cx. pipiens*, and *Cx. tarsalis*—were significantly decreased by the inclusion of the full-spectrum LED light. In contrast, all the other traps were generally neutral and equivalent to the base model trap, with but a few circumstantial differences that did not replicate across habitat types. Because operational decisions could be made with fewer moving parts and there is little to no risk of bycatch by omitting the light, SLCMAD has elected to retain the base model trap for operations.

Our results echo the sentiments of Boze et al. (2021) in that light sources of various types may not be clearly essential, depending on which species are the focus of the program in question. It is important to consider what species may be driven towards light or

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away from it (Reisen et al. 1983, Boze et al. 2021), or how mosquito preferences shift with various light wavelengths (Costa-Neta et al. 2017). For example, *Cx. quinquefasciatus* in subtropical Tanzania are attracted to nonilluminated traps baited with CO_2 (Mboera et al. 2000). *Culex tarsalis* (rural) and *Cx. pipiens* (urban) are the primary vectors of concern in our study, as they are the important vectors of West Nile virus (Farajollahi et al. 2011, Rochlin et al. 2019). In the intermountain and western United States, studies have document notable declines in *Cx. tarsalis* (Reisen et al. 1983) and *Cx. pipiens* (Boze et al. 2021) collections in direct association with the light on the traps, leading to skepticism of the importance of light attractancy.

Disparities still exist, even between neighboring programs, about using lights, no lights, incandescent bulbs, LEDs, or other mechanical details. Overall, if a miniature CDC-type trap is being used, the historical data collection norms of any given mosquito control district should be sufficiently trustworthy (Sudia and Chamberlin 1962). We believe that a district should conduct what is most logical for operations without hesitancy that their traps are lacking critical components. Instead, surveillance driven decisions should be justified by costs, maintenance, logistics, and adherence to historical data norms (Silver 2007, Healy et al. 2015). Modern vector surveillance has allowed for more customization and creativity specific to the focus of a program. For example, 3D-printing has led to a simplified and cost-efficient approach to constructing traps for mosquitoes at SLCMAD (Bibbs et al. 2024), which also allowed for customization in our current study for lights and other lures. In our study, the footprint of the heat film was small and may have been a difficult point-source to detect from a distance or the wrong approach. A modified or different attraction system design may be able to improve the omnidirectionality of a heat lure.

Generally, surveillance should prioritize the collection of vector species. However, it would be welcome to discover creative developments that can attract vectors while also not sacrificing overall diversity (Achee et al. 2019). Even basic trap components like CO_2 positioning and emission rates may impact diversity during trapping (Spitzen et al. 2008). As a result of modern technology, mosquito traps can be updated in numerous innovative ways when necessary to harmonize specific model usage. Although standardization across a large geographic area would provide added benefits for analyses, we recommend that mosquito control programs continue to utilize vector surveillance traps that are available to them because the negligible differences in trap counts may not alter operational control decisions, especially when viewed in a historical context.

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Author Contributions

Alexandra Harker (Investigation [equal], Methodology [equal], Writing—original draft [lead], Writing—review & editing [lead]), Kelsey Fairbanks (Data curation [equal], Investigation [equal], Methodology [equal], Validation [equal], Writing—review & editing [supporting]), Andrew Dewsnup (Conceptualization [equal], Methodology [equal], Resources [lead], Software [equal], Visualization [lead]), Ary Faraji (Project administration [supporting], Resources [lead], Writing—review & editing [equal]), and Christopher Bibbs (Conceptualization [supporting], Data curation [lead], Formal analysis [lead], Investigation [supporting], Methodology [equal], Project administration [lead], Resources [equal], Supervision [lead], Visualization [lead], Writing—original draft [supporting], Writing—review & editing [equal])

Supplementary material

Supplementary material is available at *Journal of Medical Entomology* online.

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