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Ryan S. Zemel
Hillsdale College

David Houghton
Hillsdale College, dhoughton@hillsdale.edu

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The Ability of Specific-wavelength LED Lights in Attracting Night-flying Insects

Ryan S. Zemel[1] and David C. Houghton[1*]

[1]Department of Biology, Hillsdale College, 33 East College Street, Hillsdale, MI 49242

Abstract

This paper describes a portable collecting light, designed by the authors, that weighs 0.3 kg, is powered by 8 AA batteries, and uses 9 light-emitting diodes (LEDs) to attract night-flying insects. Five different wavelengths of these LED lights, all within the long-wave ultraviolet spectrum, were compared to each other and to a commercially-available 15w fluorescent ultraviolet tube light for their abilities to collect insects over a series of 5 nights in July 2016. There was no difference in order richness, total specimen abundance, or the specimen abundance of most common orders between any of the wavelengths tested. Most LED wavelengths, however, caught fewer Diptera specimens than the fluorescent tube light, largely due to a lower abundance of chironomid midges. Differences in specimen abundance were greater based on sampling date or specific sampling location than based on type of collecting light. Due to their greater portability and possibly lower bycatch of Diptera, these new LED lights are presented as a potential alternative to ultraviolet tube lights.

Keywords: Light, emitting, diode, LED, night, insect, attraction

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Night-flying insects are frequently collected using fluorescent ultraviolet tube lights. While these devices are generally effective, they are cumbersome to carry due to the bulky and heavy power supply. A standard 15w light typically requires a bulky lead acid battery weighing 7–8 kg. Thus, such lights are not realistic for remote field conditions where hiking long distances with multiple lights are required.

Light-emitting diodes (LEDs) have potential as insect collecting devices due to their small size and weight, long life span, and low power needs (Price and Baker 2016). Moreover, LEDs are available in many different wavelengths, allowing for potential specificity in the insects attracted (Chu et al. 2003, Nakamoto and Kuba 2004, Chen et al. 2004, Longcore et al. 2015). Several recent studies (Green et al. 2012, Pawsen and Bader 2014, Price and Baker 2016) have indicated the efficacy of various configurations of LEDs relative to fluorescent tube lights. The objective of this research was to design our own LED ultraviolet light and to test the ability to catch night-flying insects of this light against fluorescent tube lights. We also tested several different wavelengths of LEDs within the long-wave ultraviolet spectrum to ascertain if small differences in wavelength would affect capture ability.

*Corresponding author: (email: david.houghton@hillsdale.edu).

Materials and Methods

Light housings were made from commercially-available clear high density polyethylene (HDPE) tubes of 3.8 cm diameter (www.uline.com) (Fig. 1A). Tubes were cut into 31 cm sections and fitted with watertight caps at both ends. One cap was drilled for insertion of the power switch and then sealed with watertight adhesive. Six 3-watt LEDs (~3.2–3.8V, 700 mA) were glued in an alternating manner at either ~45º or ~180º angles along a 1 cm diameter polyvinyl chloride (PVC) tube inserted into the housing. Three additional LEDs were glued onto the face of the battery pack. The battery pack was wired to three 10w constant current (900 mA) drivers to maintain a steady light output. Each driver was wired to three of the LEDs (Fig. 1B). Each light thus consisted of 9 LEDs of a particular ultraviolet wavelength. A completed light (Fig. 1C), including the 8 1.5V AA alkaline batteries needed to run it, weighed 0.3 kg. A completed light took 2–3 hours to construct, did not require any complex circuitry, and cost between $13.00 and $25.00 for parts, depending on the cost of the specific LED bulbs.

Ultraviolet wavelengths of our purchased LED bulbs were confirmed by using a Red Tide Spectrometer (www.oceanoptics.com) and LoggerPro 3 software (www.vernier.com). Each individual bulb was placed inside its HDPE tube 30 cm above the spectrometer, aimed downwards, and its intensity at wavelengths 350–450 nm recorded. We

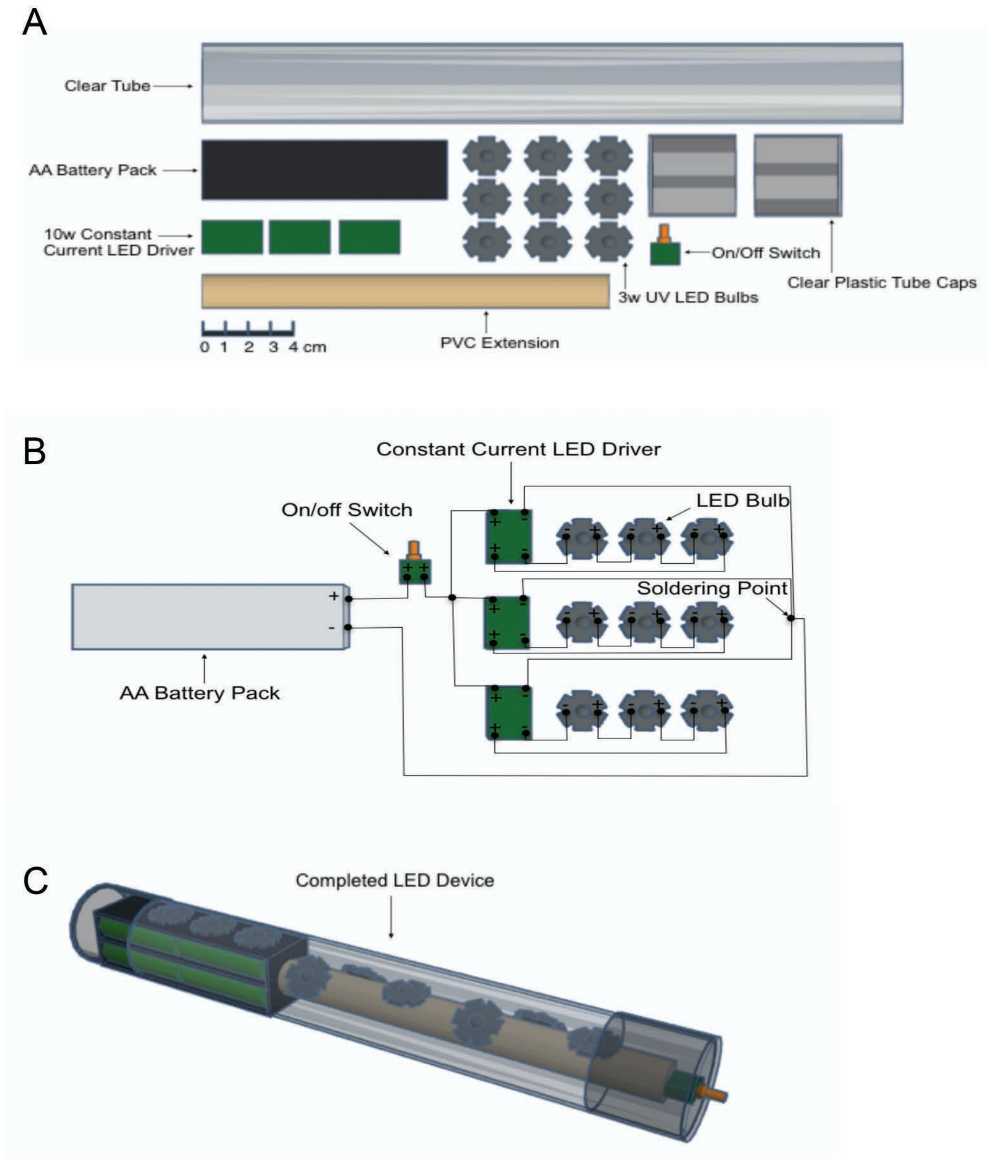

Figure 1. Components of the collecting lights (A), wiring schematic (B), and completed light (C).

did likewise with a commercially available 12V, 15w, fluorescent ultraviolet tube light (www.bioquip.com, model #2805). Although we purchased bulbs of 7 different advertised LED wavelengths, only 5 were actually found: 380, 385, 390, 395, and 403 nm (Fig. 2). The fluorescent ultraviolet tube light had several peaks of intensity. Our experimental lights consisted of the 5 determined LED wavelengths and the fluorescent tube.

Field testing of the lights was conducted during the nights of 19, 21, 22, 25, and 26 July 2016 adjacent to a ~400m section of Fairbanks Creek, located in northwestern Lower Michigan (N 44.04º, W 85.67º). Due to historical (>15 ybp) agriculture at the site, riparian vegetation was primarily grasses and sedges (*Carex* spp.), with some young pines (*Pinus strobus* L, *P. resinoa* Aiton) and oaks (*Quercas* spp.). More thorough recent descriptions and previous research at this

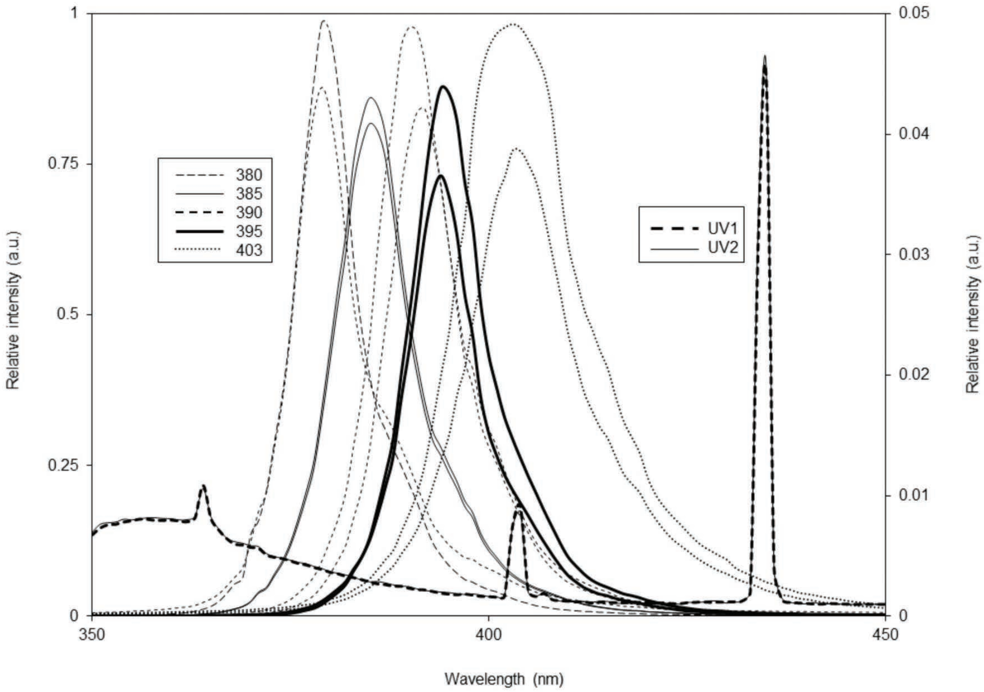

Figure 2. Peaks of light intensity within the 350–450nm range for the 10 LED (primary axis) and 2 fluorescent UV (secondary axis) bulbs tested. Intensity is in arbitrary units (a.u.), because bulbs were tested to confirm their primary wavelengths only. Thus, the spectrophotometer was not calibrated for absolute intensity, precluding any meaningful comparison of intensity between bulbs.

site can be found in Houghton and Wasson (2013), Brakel et al. (2015), and Houghton (2015).

Lights were tested at 12 sampling locations along the stream, each separated by ~15m. Two light traps of each of the 5 LED wavelengths and 2 of the fluorescent tube lights were placed randomly within the 12 sampling locations over the 5 evenings. Thus, different treatments were in different locations on different evenings. Each light was set on top of a 24×30 cm white plastic pan filled with 80% EtOH and placed ~1 m from the water's edge. Lights were simultaneously turned on at 10:20 pm and turned off at 12:20 am. Sampling occurred on evenings with daytime temperatures >25°C and with no precipitation within 2h of dusk or during the sampling period. Batteries were replaced in each light after every 2h trial.

Collected specimens were identified to the order level and counted. Mean total specimen abundance per wavelength was compared with a 1-way Analysis of Variance (ANOVA) with a *post-hoc* Tukey test. Specimen abundance per wavelength within the 7 most abundant orders: Coleoptera, Diptera, Ephemeroptera, Homoptera, Hymenoptera, Lepidoptera, and Trichoptera was also compared via 1-way ANOVA. Mean specimen abundance, as well as specimen abundance for each of the above 7 orders, were also analyzed per sampling location and per date with individual 1-way ANOVAs. Mean order richness per wavelength was analyzed with a Mann-Whitney U test since the distribution violated parametric assumptions. Individual correlations with total specimen abundance were determined for LED wavelength, and maximum temperature and dew point for the collecting day.

Results

There was no difference in either mean specimen abundance or mean order richness between the 5 LED wavelengths or the fluorescent ultraviolet light. There was no difference in mean specimen abundance of the 7 most abundant orders between the lights except for the Diptera, which exhibited some statistical overlap (Table 1). Wavelength exhibited a weak negative correlation (r = 0.45) with total number of specimens caught. The 21 July sampling night had both the highest mean specimen abundance for all orders combined and the highest specimen

Table 1. Mean number of specimens from the 7 most abundant insect orders, and mean total number of orders, based on wavelength during the 5 nights of our study. Asterisks represent statistically distinct groups of means based on a 1-way Analysis of Variance with a post-hoc Tukey test. For number of orders, a Mann-Whitney U test was used due to the non-normal distribution. 'UV' = ultraviolet fluorescent bulb.

	Wavelength						
	380	**385**	**390**	**395**	**403**	**UV**	*p*
Coleoptera	33.0	27.2	20.0	39.0	34.3	29.2	0.93
Diptera	342.3^{a}	232.9^{ab}	88.7^{b}	187.3^{ab}	161.5^{ab}	433.4^{a}	**0.03**
Ephemeroptera	21.2	10.6	8.2	13.4	14.5	9.0	0.59
Homoptera	120.4	99.1	78.8	107.7	72.7	107.1	0.59
Hymenoptera	15.2	13.9	8.8	14.5	11.2	13.7	0.98
Lepidoptera	421.7	300.6	162.4	245.4	257.8	374.6	0.66
Trichoptera	169.2	136.3	151.9	140.3	75.2	139.1	0.51
Combined	1142.3	840.0	533.2	768.8	650.1	1123.8	0.42
Number of orders	9.6	9.3	9.5	9.7	9.5	9.5	0.70

abundance for each individual order except Ephemeroptera (Table 2). Total number of specimens caught per sampling night did not correlate with maximum temperature ($r < 0.01$), and only weakly ($r = 0.51$) with dew point. Mean specimen abundance for all orders combined was not different between sampling locations. The Ephemeroptera and Trichoptera, however, both had higher mean specimen abundance at the 2 most downstream sampling sites (Table 3).

Discussion

Our results clearly indicated the viability of LEDs in catching night-flying insects, as both specimen abundance and order richness were comparable to that of fluorescent ultraviolet lights. This result is similar to that of Green et al. (2012), who found no significant difference in the total number of specimens caught between ultraviolet LED and fluorescent lights. Similarly, Price and Baker (2016) found that their designed LED collecting light compared "favorably" to fluorescent ultraviolet lights. Although no statistical comparisons were performed, the LED lights collected a greater overall number of insect orders than fluorescent lights. Both of these studies tested LED bulbs of ~395 nm.

Our results also suggested that subtle wavelength differences within the long-wave ultraviolet spectrum were generally not important in attracting night-flying insects with LED lights. Ours appears to be the first study to specifically address these differences within the ultraviolet spectrum. Previous studies either tested a single ultraviolet wavelength (typically ~395 nm) or else compared ultraviolet LEDs to white LEDs (Green et al. 2012, Pawsen and Bader 2014, Price and Baker 2016). Although there were some differences in specimen abundance

Table 2. Mean number of specimens from the 7 most abundant insect orders based on collecting date for all lights tested. Asterisks represent statistically distinct groups of means based on a 1-way Analysis of Variance with a post-hoc Tukey test. Weather data from www.wunderground.com.

	19 July	**21 July**	**22 July**	**25 July**	**26 July**	***p***
Maximum temperature	26.1	28.3	32.2	27.8	29.4	N/A
Dew point	11.7	19.4	17.2	17.3	14.4	N/A
Coleoptera	6.0^{b}	101.6^{a}	26.8^{b}	7.6^{b}	10.3^{b}	**<0.01**
Diptera	123.7^{b}	610.0^{a}	173.8^{b}	167.8^{b}	129.8^{b}	**<0.01**
Ephemeroptera	10.3^{ab}	5.2^{b}	17.5^{ab}	24.5^{a}	6.7^{ab}	**0.03**
Homoptera	53.3^{b}	169.6^{a}	145.4^{a}	54.5^{b}	65.4^{b}	**<0.01**
Hymenoptera	2.8^{b}	47.5^{a}	5.8^{b}	3.6^{b}	4.8^{b}	**<0.01**
Lepidoptera	103.2^{b}	927.2^{a}	159.5^{b}	138.7^{b}	140.3^{b}	**<0.01**
Trichoptera	95.4^{b}	247.4^{a}	126.2^{b}	90.8^{b}	116.8^{b}	**<0.01**
Combined	394.7^{b}	2108.5^{a}	655^{b}	487.5^{b}	474.1^{b}	**<0.01**

Table 3. Mean number of specimens from the 7 most abundant insect orders based on sampling location for all lights tested during the 5 nights of our study. Asterisks represent statistically distinct groups of means based on a 1-way Analysis of Variance with a post-hoc Tukey test. Lower-numbered sites were downstream of higher-numbered sites.

Sampling location	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	*p*
Coleoptera	66.0	39.2	45.8	26.6	25.8	33.2	24.4	16.0	14.0	11.0	26.6	36.8	0.86
Diptera	531.2	252.8	269.6	147.0	310.0	242.2	197.8	175.4	163.8	124.8	266.0	211.6	0.63
Ephemeroptera	42.4[a]	28.0[ab]	12.0[b]	10.8[b]	8.8[b]	7.0[b]	10.4[b]	8.2[b]	6.6[b]	6.4[b]	5.6[b]	7.6[b]	**0.01**
Homoptera	157.8	112.8	116.4	76.4	90.8	91.6	70.2	65.2	78.8	78.8	99.4	133.4	0.59
Hymenoptera	14.2	11.4	15.6	10.6	20.0	15.2	14.4	12.8	14.0	7.8	13.4	9.2	0.99
Lepidoptera	365.4	329.4	341.8	258.6	370.4	254.0	217.6	307.4	167.8	151.4	358.6	402.6	0.99
Trichoptera	348.8[a]	151.4[b]	100.8[b]	95.4[b]	102.2[b]	125.8[b]	96.2[b]	98.8[b]	108.4[b]	136.6[b]	100.2[b]	159.4[b]	**0.04**
Combined	1525.8	925.0	902.0	625.4	928.0	769.0	630.9	683.8	553.4	516.8	869.8	960.6	0.83

between our ultraviolet wavelengths, these differences were not significant and were much smaller than differences between collecting dates. Specific trap placement was also more important than wavelength for the aquatic orders Ephemeroptera and Trichoptera. This observation is not surprising considering the importance of stream microhabitat in affecting aquatic insect distributions (Houghton and Wasson 2013). These results collectively suggest that natural variation in field conditions are more important in affecting trap catches than the specific ultraviolet wavelength that we used. Longcore et al. (2015) similarly found that collecting site, temperature, and humidity were as important in attracting insect specimens as was spectral composition of the white LEDs.

It is not clear why our LED lights generally caught fewer specimens of Diptera than did the fluorescent ultraviolet light. Trends in most of our data exhibited a bimodal distribution: high specimen abundance at 380 nm, low at 390, and high again at 403 and with the fluorescent ultraviolet light. For most data, however, results were not statistically significant. Chironomid midges were present in large numbers during several sampling nights. It may be that the statistical significance of the Diptera data is simply due to the larger numbers increasing the statistical power of the test (Zar 2010). Numbers of Lepidoptera specimens, however, were even higher than those of Diptera, and yet did not exhibit a significant difference between wavelengths.

It is possible that the 15m space between our traps led to some overlapping attraction. Van Grusven et al. (2014) found that a 5w fluorescent light attracted Lepidoptera specimens released up to 50m away from it. They also found that that attraction decreased markedly as distance increased from 10m to 25m, suggesting that any overlapping attraction between our traps was fairly minor.

Some potential sources of error existed within our study, primarily due to the commercial, rather than scientific, origin of our light components. First, it was not possible to obtain detailed specification data or quality control information about our LED bulbs, as they were unbranded and shipped directly from the People's Republic of China via www.ebay.com. As mentioned earlier, only about half of the bulbs that we received emitted their advertised ultraviolet wavelength. The effect of bulb light intensity was not clear, as we were not able to calibrate our spectrophotometer within acceptable tolerances to obtain absolute intensity data between bulbs (Fig. 2). The order of magnitude difference between LED and fluorescent bulbs, however, as well as the nearly identical intensity values of the 2 fluorescent bulbs do suggest light intensity differences between the 2 bulb types and, possibly, between some of the LED bulbs. Such differences may have affected insect catch. Lastly, information on potential UV light attenuation by the HDPE tubes that we used for light housings was not available. Better quality control and information would allow us to view our results with greater confidence.

Further research will be needed to address the potential lower bycatch of Diptera with particular wavelengths, as well as any other potential specific responses in other insect orders. Further, while we noticed no loss of light intensity during our 2-hour field trials, preliminary research suggested a loss of such intensity during longer trials. Thus, battery life may need to be addressed for longer field situations. Lastly, a center tube composed of aluminum instead of PVC may be necessary for longer trials to combat potential heat build-up.

Despite these potential issues, our LED collecting light was as effective as a commercially available fluorescent ultraviolet light in collecting night-flying insects. Our lights are ~1/5th of the cost of such lights, <1/20th of the weight when factoring in both light and power supply, run on self-contained AA batteries, and are fairly easy to build. Several can easily be carried in a backpack to remote collecting sites. Thus, these lights appear to be viable alternatives to ultraviolet fluorescent lights.

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