Phototaxis of Fungus Gnat, *Bradysia* sp. nr *coprophila* (Lintner) (Diptera: Sciaridae), Adults to Different Light Intensities

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Abstract. Multiple-choice experimental arenas, with sample compartments, were used to assess the response of fungus gnat, *Bradysia* sp. nr. *coprophila* (Lintner) (Diptera: Sciaridae), adults to varying light intensities in environmentally controlled walk-in chambers. Each sample compartment contained a yellow sticky card (2.5 × 2.5 cm) to capture fungus gnat adults. Under conditions of darkness, fungus gnat adults migrated randomly with no significant differences among the six sample compartments. Fungus gnat adults were observed to positively respond to light intensities less than 0.08374 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$. In addition, adults responded to light intensities that were below the detection threshold of a photosynthetically active radiation light sensor. A higher percentage of fungus gnat adults (22% to 39%) were captured on yellow sticky cards in the sample compartments that were closest to a directional light source compared with sample compartments that were located further away from the light source (2% to 9%). Fungus gnat adults exhibited a significant response when exposed to two distinct ranges of light intensities (0.12 to 0.26 versus 0.87 to 1.02 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$) with adults significantly more attracted to the highest light intensities (0.87 to 1.02 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$). The results obtained in this study indicate that fungus gnat adults are positively phototactic, and as light intensity increases, they display a preference for those higher light intensities. It is possible that modifications in light intensity may be a feasible management strategy for alleviating problems with fungus gnats in greenhouses.

Phototaxis is movement in response to light and is a common behavioral trait of many insect species (Dreisig, 1980; Hollingsworth et al., 1964; Persson, 1971; Sivinski, 1998). This response may be influenced by light quality and light intensity (Danilevskii, 1965; Menzel and Greggars, 1985). Insects are often attracted to light sources, particularly artificial lighting (Barrett et al., 1971; Kolligs, 2000; Vanninen and Johansen, 2005). Certain Hymenoptera species have been shown to orient toward light sources emitting either high or low light intensities (El-Helaly et al., 1981; Gu and Dorn, 2001; Menzel and Greggars, 1985; Sivinski, 1998; Turlings

et al., 2004; van Lenteran et al., 1992; Zilahi-Balogh et al., 2006); however, at higher light intensities, there may be no apparent directional effects or insects simply may not be attracted to higher light intensities (Deay, 1950; Zolotov, 1989). As such, it appears that insects exhibit a diminishing response to increased “brightness” or light intensity (Hartsock, 1961). Many Diptera, including both adults and larvae, may exhibit strong phototactic behavior (Glick and Hollingsworth, 1955; Jacob et al., 1977; Sivinski, 1998). In fact, light traps have been used to collect fungus gnat species in the family Mycetophilidae (Mikolajczyk, 2001).

Fungus gnats, *Bradysia* spp. (Diptera: Sciaridae), are major pests in greenhouses (Dennis, 1978; Hamlen and Mead, 1979). Although fungus gnat adults cause minimal plant damage (Cloyd, 2000), the females lay eggs, which hatch into larvae that directly damage plants by feeding on root tissue in the growing medium, thus disrupting the

uptake of water and nutrients (Fawzi and Kelly, 1982; Hungerford, 1916; Leath and Newton, 1969; Wilkinson and Daugherty, 1970). Fungus gnat adults are weak fliers, primarily inhabiting the environment near the growing medium surface (Hungerford, 1916).

Fungus gnat adults are attracted to light; in greenhouses, they often gather on or near windows after emergence (Karren and Roe, 2000). Liu et al. (2004) reported that light intensities of 500 lx (6 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$) and 1500 lx (18 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$) influenced male fungus gnat, *Bradysia paupera* Tuomikoski (Diptera: Sciaridae), mating behavior and upwind flight movement to extracts of the female sex pheromone. However, no studies have quantified the effect of light intensity on the phototactic behavior of the fungus gnat *Bradysia* sp. nr. *coprophila* (Lintner) (Diptera: Sciaridae). The purpose of this study was to determine the relative attractiveness of light intensity to fungus gnat adults and assess a relationship between light intensity and adult fungus gnat response.

Materials and Methods

A set of five six-armed experimental arenas was used in this study (Fig. 1). Each experiment was repeated twice, on separate days, with each set of five experimental arenas used simultaneously such that the number of replicates for the respective experiments was 10. Each experimental arena consisted of a central compartment made from a round, clear, 5.3-L polypropylene microwavable container (Flex & Seal; Rubbermaid, Fairlawn, OH) with a snap-on lid. Six round holes, 3.8 cm in diameter, were drilled into the sides of the central compartment equidistant from each other. Every hole was fitted with a cylindrical, acrylic plastic, hollow sleeve (2.8 cm in length with an internal diameter of 3.0 cm). These sleeves were permanently affixed to the central compartment with plastic cement. Hollow, clear acrylic tubes (internal diameter of 2.5 cm) were cut 11.2 cm in length and fitted inside each sleeve. Six smaller compartments, referred to as sample compartments, were attached to the end of each acrylic tube using the same sleeve as described previously. These sample compartments were clear, square, 1-L polycarbonate microwavable containers (Rubbermaid Stain Shield; Rubbermaid) with snap-on lids.

Previous research in our laboratory indicated that studies using these experimental arenas to test for fungus gnat adult attractiveness to volatiles emitted from growing medium were influenced by variations in light intensities under laboratory conditions (22 ± 2 °C and 50% to 60% relative humidity).

Fungus gnat adults used in all subsequent experiments were obtained from laboratory colonies reared in SB300 Universal Professional Growing Mix (Sun Gro Horticulture, Bellevue, WA) soilless growing medium located at the University of Illinois, Urbana, IL (Cabrera et al., 2005). Specimens from the

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Fig. 1. Six-armed experimental arena used for all experiments in the study. Adult fungus gnats, *Bradysia* sp. nr. *coprophila*, obtained from a laboratory colony, were collected in a plastic vial and then placed into the central compartment (A). A small petri dish supporting a 2.5 × 2.5-cm yellow sticky card was placed into each sample compartment (B). The number of adult fungus gnats captured on the yellow sticky cards was used to measure attractiveness of light intensity.

colony were identified as *Bradysia* sp. nr. *coprophila* (Linter) by Raymond J. Gagne, Systematic Entomology Department Laboratory, U.S. Department of Agriculture. Voucher specimens are located in the Illinois Natural History Survey Insect Collection (#22896-22932, 32015-32021). One hundred 6- to 9-day-old fungus gnat adults (random mixture of females and males) were released into the central compartment of each experimental arena. Adults were aspirated into a 9-dram vial. The vial was placed in the central compartment of the experimental arena, the lid of the vial was removed, and then the lid of the central compartment was quickly closed.

A 2.5 × 2.5-cm yellow sticky card (Whitmire MicroGen, St. Louis) was placed in the center of each sample compartment to capture fungus gnat adults once they had entered the sample compartment. Yellow sticky cards were placed (horizontally) in the sample compartments so as to avoid biasing fungus gnat adult attraction into the sample compartments. The experiments were conducted for 48 h after which time the number of fungus gnat adults per yellow sticky card was recorded.

Light readings were taken just before releasing fungus gnat adults into the central compartment of each experimental arena. A photosynthetically active radiation (PAR) sensor providing output to a LI-COR brand LI-1000 DataLogger (LI-COR, Lincoln, NE) was centrally positioned on top of the lid of each sample compartment, which recorded readings in $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$.

Statistical analyses. The percent of fungus gnat adults captured on the yellow sticky cards in each sample compartment were analyzed using a Statistical Software Program for Windows, version 8.2. The data were normalized by arsine square-root transformation and subject to a one-way analysis of variance with sample compartment as the main effect (SAS Institute, 2002). Significant sample compartment means were separated using a Fisher's protected least significant difference test at $P \leq 0.05$ (SAS Institute, 2002). All data presented are nontransformed.

Expt. 1: Fungus gnat, *Bradysia* sp. nr. *coprophila* adult response in the absence of light. This experiment, using all six sample compartments of the experimental arenas, was conducted in an environmentally controlled walk-in chamber (3-m long × 1-m wide × 2-m tall) with a white interior located in the National Soybean Research Center, Urbana, IL, with a temperature of 24 ± 3 °C. As soon as the fungus gnat adults were released into the central compartment of all experimental arenas ($n = 5$), the lights were turned off and remained off for the duration of the experiment (48 h).

Expt. 2: Fungus gnat, *Bradysia* sp. nr. *coprophila* adult response to an incandescent light source. The procedures for this experiment were similar to those described previously; however, in this experiment, we wanted to determine if fungus gnat adults would be attracted to directional light using an already existing light source in a similarly designed environmentally controlled walk-in

chamber (3-m long × 1-m wide × 2-m tall) with a white interior. The incandescent light source was recessed and located in one corner of the chamber, which had a sliding door panel to reduce light emission. The actual bulb was not accessible from inside the chamber, so we were unable to determine the brand/type of bulb. We conducted this experiment with the panel covering the light source. Providing a directional or point light source would result in the sample compartments receiving different light intensities and produce a continuum to detect a response within the experiment. The experimental arenas were always arranged in the walk-in chamber such that sample compartments 1 and 2 were closest to the light source; sample compartments 3 and 6 were the next closest; and sample compartments 4 and 5 were located furthest away from the light source. After closing the panel, it was no longer possible to detect any visible light; however, we measured light intensity by placing the sensor directly on the panel.

Expt. 3: Fungus gnat, *Bradysia* sp. nr. *coprophila* adult attraction to an incandescent light source. The procedures used in this experiment were similar to those described in the previous two experiments. This experiment, using all six sample compartments of the experimental arenas, was conducted in the same environmentally controlled walk-in chamber as used in Expt. 2. This experiment was designed to determine if fungus gnat adults would be attracted to the same directional light source used in Expt. 2, except in this case, we conducted the experiment with the panel open. We measured the light intensity with the sensor placed directly at the source and on the lid of each sample compartment.

Expt. 4: Fungus gnat, *Bradysia* sp. nr. *coprophila* adult response to a fluorescent light source. The general procedures used in this experiment were similar to those described in the previous experiments. However, we used the same environmentally controlled walk-in chamber as in Expt. 1. In this experiment, a fluorescent light (GE F48T12 cool white/high output, Fairfield, CT), located in one corner of the environmentally controlled walk-in chamber, remained on during the 48-h time period providing a directional light source. The experimental arenas were arranged similarly like in previous experiments and light intensity was measured as in Expts. 1 and 2. A regression analysis using PROC REG procedures (SAS Institute, 2002) was conducted to assess the influence of light intensity in attracting fungus gnat adults. However, before conducting the regression analysis, data were normalized by arsine square-root transformation. All data presented are nontransformed.

Expt. 5: Fungus gnat, *Bradysia* sp. nr. *coprophila* adult response to two distinct light intensities. This was a two-choice experiment. Four of the six sample compartments were not used so the openings were sealed with laboratory film (parafilm; Pechiney Plastic Packaging, Menasha, WI). A

yellow sticky card was placed into each of two sample compartments of each experimental arena, one ≈ 47 cm from the light source and the other one ≈ 90 cm away from the light source. The light source was a fiberoptic illuminator equipped with two gooseneck arm lights (Fiber-Lite MI-150 Illuminator, Dolan-Jenner, Ind., Lawrence, MA) with an Ushio halogen bulb (150 W and 21 V) per gooseneck arm. The illuminator was placed on the floor of the environmentally controlled walk-in chamber (2-m long $\times$ 1-m wide $\times$ 2-m tall), which had a white interior, and arranged so that the light source was centrally located among the five experimental arenas. The light unit was set at the highest intensity, which was equivalent to $\approx 60,000 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$. The two gooseneck arms were positioned vertically, close together, so that light was directed toward the ceiling. Light measurements were taken and recorded as described previously with the sensor positioned centrally on the lid of each sample compartment just above the location of the yellow sticky cards. Data were collected as described in the previous experiments and normalized by arsine square-root transformation before being analyzed using a *t* test procedure (SAS Institute, 2002). All data presented are nontransformed.

Results

Expt. 1: Fungus gnat, Bradysia sp. nr. coprophila adult response in the absence of light. Fungus gnat adults migrated randomly in total darkness because there were no significant differences ($F = 0.87$; $\text{df} = 5, 59$; $P = 0.507$) in the percent of fungus gnat adults present (16% to 20%) in each sample compartment.

Expt. 2: Fungus gnat, Bradysia sp. nr. coprophila adult response to an incandescent light source. We recorded light intensity levels between 0.00 and $0.00486 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ when the sensor was placed directly on the panel. Significantly more fungus gnat adults were recovered in the sample compartments closest to the light source (1 and 2) than the other sample compartments (Table 1).

Expt. 3: Fungus gnat, Bradysia sp. nr. coprophila adult attraction to an incandescent light source. We recorded a light intensity of $0.08374 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ when the sensor was positioned directly at the source. However, when we attempted to measure the light intensity on the lid of the sample compartments, the light intensities were below the detection threshold of the sensor. Numerically, more fungus gnat adults were recovered in the sample compartments closest to the light source (1 and 2) than the other sample compartments (Table 1). However, in this case, sample compartment 6 was not significantly different from sample compartment 2, whereas sample compartment 3 was not significantly different from the sample compartments furthest away from the light source (4 and 5) (Table 1).

Table 1. Mean ($\pm$ SE) percent fungus gnat, *Bradysia sp. nr. coprophila*, adults captured on yellow sticky cards (2.5×2.5 cm) in the sample compartments (1 through 6) of each experimental arena for Expts. 2 through 3.^z

Compartment	n	Mean ($\pm$ SE) percent fungus gnat adults captured ^y	
		Expt. 2 (low light)	Expt. 3 (visible incandescent)
1	10	40 $\pm$ 5 a	34 $\pm$ 2 a
2	10	39 $\pm$ 7 a	22 $\pm$ 3 b
3	10	9 $\pm$ 2 b	11 $\pm$ 2 c
6	10	8 $\pm$ 2 b	17 $\pm$ 2 b
4	10	2 $\pm$ 0 b	9 $\pm$ 1 c
5	10	2 $\pm$ 1 b	7 $\pm$ 1 c

^zExperimental arenas were arranged such that sample compartments 1 and 2 were closest to light source, 3 and 6 were next closest to light source, and 4 and 5 were furthest away from the light source.

^yMeans followed by a common letter within a column are not significantly different ($P \leq 0.05$) as determined by Fisher's protected least significant difference test.

Expt. 4: Fungus gnat, Bradysia sp. nr. coprophila adult response to fluorescent light source. The results of the correlation analysis indicated that the percent fungus gnat adults captured on the yellow sticky cards was significantly positively correlated with light intensity ($F = 11.03$; $\text{df} = 1, 59$; $P = 0.0016$; $r^2 = 0.15$; slope = 0.061; SE = 0.018; and intercept = -0.003) when adults were exposed to a range of light intensities (1.66 to $3.94 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$).

Expt. 5: Fungus gnat, Bradysia sp. nr. coprophila adult response to two distinct light intensities. Fungus gnat adults exhibited a significant response ($F = 2.82$; $\text{df} = 9, 28$; $P < 0.0001$) based on the percent of fungus gnat adults recovered in the sample compartments when exposed to two distinct light intensity ranges (0.12 to 0.26 versus 0.87 to $1.02 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$). A significantly higher percentage of fungus gnat adults (81 ± 4 ; mean $\pm$ SE) were recovered in sample compartments exposed to light intensities between 0.87 and $1.02 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ than the percentage of fungus gnat adults (19 ± 4 ; mean $\pm$ SE) recovered in sample compartments exposed to light intensities between 0.12 and $0.26 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$.

Discussion

This study has distinctly demonstrated that fungus gnat, *B. sp. nr. coprophila*, adults disperse in a random or haphazard manner in the absence of light. In addition, fungus gnat adults, in general, were attracted to light intensities less than $0.08374 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ as demonstrated in Expts. 2 and 3 in which the sample compartments closest to the light source (1 and 2) had numerically and consistently higher percentages of adult fungus gnats than the other sample compartments (Table 1).

It has been hypothesized and demonstrated that the number of insects captured in light traps is enhanced as light intensity increases (Frost, 1970). Barr et al. (1960) reported that the number of mosquitoes [*Aedes nigromaculis* Ludlow (Diptera: Culicidae)] collected in light traps was directly proportional to light intensity. The light intensities tested were 42, 110, and 150 foot-candles, which are equivalent to 6.3, 16.5, and $22.5 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$, respectively.

These light intensities were much higher than those measured in our study.

Light intensity has been implicated as a factor responsible for attracting insects to light traps (Baker and Sadovy, 1978; Barr et al., 1960; Frost, 1970; MacDowell, 1972; Persson, 1971). However, there is minimal, if any, information available associated with the effect of light intensity on fungus gnat adult behavior; although, when given a choice, fungus gnat adults tended to migrate toward the "higher" light intensities (0.87 to $1.02 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$) as demonstrated in Expt. 5. Moriarty (1959) reported that moths of *Anagasta kuhniella* Zeller (Lepidoptera: Pyralidae) were more active at "high light intensities." It is possible that certain species of Diptera and Lepidoptera may respond similarly to "high light intensities."

Insects may also respond differently to light intensity depending on the distance from the light source (Bowden, 1982). Because we were evaluating fungus gnat adult behavior primarily under light intensities that were below the detection threshold of a PAR light sensor or in total darkness, distance was likely not a factor in influencing the response of the fungus gnat adults.

The results obtained in this study may be useful in managing fungus gnats in greenhouses, for example, by using bright lamps in conjunction with traps. In fact, Liu et al. (2004) indicated that light, along with the use of pheromone traps, may be a feasible management strategy for controlling fungus gnats in greenhouses. However, it is important to note that extrapolating laboratory results, which typically involve artificial lighting, to greenhouse conditions may not be entirely appropriate as a result of factors such as natural sunlight, reflected light, and background illumination or a combination of these factors, which may influence insect response to light. In addition, insect attraction may be the result of the type of light source (e.g., mercury vapor, incandescent, fluorescent, or ultraviolet lamps). As a result, it may be interesting to explore the possibility of using artificial light sources in combination with traps during the evening to reduce competition from other light sources.

This study provides a starting point for evaluating the response of fungus gnat adults to varying light intensities. In addition,

certain Lepidoptera species, including the corn earworm, *Heliothis zea* Boddie (Lepidoptera: Noctuidae), have been reported to be more attracted to light emitted in the ultraviolet spectrum compared with emissions in the longer wavelengths (Deay et al., 1965). Fungus gnat adults may possess photoreceptors that are sensitive to low light intensities, even those not detectable by PAR sensors, or they may be more attracted to specific wavelengths of light; for example, wavelengths, in the solar ultraviolet region, not detectable by visible light sensors (280 to 380 nm) appear to be most attractive to insects (Frazier, 1985; Mellor et al., 1997; Mikkola, 1972; Young et al., 1987).

It should be noted that in this study, we only measured light intensity, not light quality. As such, it is possible that light intensity may be confounded with light quality. Despite this, fungus gnat adults are positively phototactic and exhibit a clear preference for any light intensity over darkness. Furthermore, as light intensity increases, fungus gnats display a preference for those higher light intensities. As a result, any experiments involving fungus gnat adults must account for this behavior by either providing uniform illumination or conducting experiments in total darkness. Additionally, further studies are needed to determine whether the onset of fungus gnat adult activity is influenced by different wavelengths, various light intensities, and different light sources.

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