BIOLOGICAL AND PHYSICAL FACTORS AFFECTING CATCH OF HOUSE FLIES IN ULTRAVIOLET LIGHT TRAPS

By

MATTHEW D. AUBUCHON

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by

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Abstract of Dissertation Presented to the Graduate School of the University of Florida in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy

BIOLOGICAL AND PHYSICAL FACTORS AFFECTING CATCH OF HOUSE FLIES IN ULTRAVIOLET LIGHT TRAPS

By

Matthew D. Aubuchon

May 2006

Chair: Phil Koehler
Major Department: Entomology and Nematology

A bioassay for studying light trap efficacy for the house fly Musca domestica L. (Diptera: Muscidae) was developed to overcome position effects associated with light-trap placement. After initial studies, no significant effects of position were detected among two research buildings, four positions, or box enclosures used. The light-tunnel bioassay provided standardized air movement, trap location, trap distance, and background light for future experiments investigating house fly age and response time. House flies that were 5 d and younger showed significantly greater attraction toward UV light traps than older flies. A probit analysis estimated that catch time for 50% of house flies (CT_{50}) toward UV traps ranged from 99 to 114 min for males and females respectively. Estimated CT_{50} for total house fly response toward UV light trap was approximately 1.72 h (103.2 min). The CT_{90} and CT_{95} estimates for total house fly catch were 6.01 h (360.6 min) and 8.57 h (514.2 min) for males and females respectively. No
significant difference between male and female response time was seen by overlapping 95% confidence intervals for CT$_{50}$, CT$_{90}$, and CT$_{95}$.

When flies were presented greater intensity levels of cool-white fluorescent light, the number of males caught in UV traps significantly decreased when intensity of the competing light exceeded 51.43 lumens/m$^2$. Significant declines in catch of females occurred at a lower intensity when the competing light exceeded 27.43 lumens/m$^2$. When the data were combined, overall results showed that the total catch in UV light traps decreased significantly as the intensity of competing light source increased. Results of our lab study showed a significant decrease in response of male and female house flies toward UV light traps as the intensity of competing fluorescent light was increased.

When house flies were presented four different types of competing light, all responses were significantly different when compared with the dark control. However, house fly response toward UV light traps was significantly lower when background light contained broad-based UV versus background light containing blue-green light.

For habituation experiments, all treatments caught significantly fewer house flies than the dark control. However, there was no significant difference in the response to UV light traps among house flies reared on UV light, cool-white fluorescent light, and the grow-lights used in the rearing rooms. The quality of light used in rearing did not significantly influence house fly response to UV light traps.
CHAPTER 1
INTRODUCTION AND LITERATURE REVIEW

The House Fly *Musca domestica*

The house fly *Musca domestica* L. (Diptera: Muscidae) is a synanthropic filth fly that breeds in garbage, and animal and human feces (Schoof and Silverly 1954a, Greenberg 1973, Imai 1984, Graczyk et al. 2001). It is a dull gray insect and may be identified by four longitudinal stripes on the dorsum of the thorax and a sharp angle on the fourth longitudinal wing vein (West 1951). The house fly does not bite as it is equipped with sponging-rasping mouthparts (West 1951, McAlpine 1987).

*Musca domestica* L. is classified in the order Diptera and family Muscidae (McAlpine 1987, Borror et al. 1989). Flies in the family Muscidae generally have strong setae dispersed over the entire body, dull color, and reduced wing veination (West 1951, McAlpine 1987). The Genus *Musca* encompasses approximately 24 species with 2 subspecies of *M. domestica* (West 1951). Because house flies adapt to human environments, they are found on all continents except Antarctica (West 1951, McAlpine 1987).

Importance of *Musca domestica*

Nuisance

House flies are a nuisance in agricultural and urban environments (Cosse and Baker 1996, Moon 2002, Hogsette 2003). Large populations populations originating from animal manure can cause economic losses in livestock (Axtell 1970, Hogsette and Farkas 2000). Dispersing house flies are pestiferous in residential and commercial areas and
present a public health problem to home and business owners near agricultural areas (Axtell 1970, Hogsette 2003). Breeding sites such as animal waste and garbage dumpsters contribute to problems associated with house flies in urban environments (Schoof and Silverly 1954b, Morris and Hansen 1966).

**Disease Transmission**

House flies have been implicated as mechanical vectors of a range of enteric pathogens among animals and humans (Schoof and Silverly 1954a, Greenberg 1973, Imai 1984, Graczyk et al. 2001). Viruses, bacteria, and protozoans cling to house fly wings, setae, tarsi, and mouthparts and are dislodged onto a variety of surfaces (Graczyk et al. 2001). In poultry houses and dairy units, house flies were a primary vector of *Salmonella* spp. (Mian et al. 2002). *Salmonella* spp. and *Shigella* spp. (which causes morbidity and mortality associated with infantile gastroenteritis), are also transmitted by house flies to humans (Bidawid et al. 1978). Levine and Levine (1991) reported that the incidence of dysentery coincided with the seasonal prevalence of house flies. As house flies acquired *Shigella* spp. from human feces in open latrines, they contaminated open food markets, hospitals, slaughter houses, and animal farms (Levine and Levine 1991, Graczyk et al. 2001). A high density of open markets with rotting fish, meats, and vegetable matter combined with close proximity of food markets to slaughter houses encouraged outbreaks of house flies (Bidawid et al. 1978). Incidentally, a high density of humans lacking infrastructure and garbage pick-up compounded the health risks associated with house fly outbreaks (Bidawid et al. 1978). In addition to *Salmonella* spp. and *Shigella* spp., house flies transmit other enteric disease organisms such as *Campylobacter* spp. or enterohemorrhagic *E. coli*, which cause morbidity and mortality in humans resulting from diarrheal illnesses (Graczyk et al. 2001). Helminthic parasites have also been transported
on house fly exoskeletons and rotavirus may be transported on legs and wings, then dislodged by flight motion (Monzon et al. 1991, Tan et al. 1997).

In hospitals, house flies can play a vital role as vectors of resistant strains of enteric pathogens among patients (Rady et al. 1992). Pathogens such as *Klebsiella* spp., *Enterococcus faecalis*, and others have been distributed by house flies within patient wards (Graczyk et al. 2001). Many strains are acquired by house flies from patients and some strains are resistant to antibiotics (Graczyk et al. 2001). Rady (1992) isolated Enterobacteriaceae, Micrococcaceae, Corynebacteriaceae, Brucellaceae, and Pseudomonodaceae from house flies trapped in hospitals. Among the aforementioned families of bacteria, some may cause septicemia in humans (Rady et al. 1992).

Although house flies primarily transport disease agents on their wings, tarsi, and setae, they may also spread pathogens by regurgitation and fecal deposition (Graczyk et al. 2001). In developing countries, house flies are important vectors of *Chlamydia trachomatis*, which causes blindness in humans (Graczyk et al. 2001). Flies carry *C. trachomatis* on their legs and probosces, and the agent survives in the gut for 6 hours (Graczyk et al. 2001). In laboratory studies, *Helicobacter pylori* was isolated from external surfaces of house flies up to 12 hours after exposure (Gruebel et al. 1997). However, *H. pylori* (responsible for gastroduodenal disease), was also isolated from gut and excreta of house flies up to 30 hours after initial feeding by house flies (Gruebel et al. 1997). *Helicobacter* organisms attached to intestinal epithelial walls of house fly guts suggested that house flies were a reservoir as well as a vector (Gruebel et al. 1997). Other bacteria isolated from the digestive tract of house flies included *Klebsiella oxytoca*, *Enterobacter agglomerans*, *Burkholderia pseudomallei*, *Citrobacter freundii*, and
Aeromonos hydrophila (Sulaiman et al. 2000). Yersinia pseudotuberculosis survived in the house fly digestive tract up to 36 hours after exposure (Zurek et al. 2001). House flies may contaminate a surface with Y. pseudotuberculosis by regurgitating their crop content (Zurek et al. 2001).

Recent studies implicate house flies as vectors of Enterohemorrhagic Escherichia coli (EHEC) 0157:H7 which causes enteric hemorrhagic disease in humans. House flies acquired EHEC 0157:H7 from cow dung and were capable of transmitting EHEC 0157:H7 (Iwasa et al. 1999). The EHEC 0157:H7 proliferated in mouthparts of house fly where it may be ingested and disseminated by fecal deposition (Sasaki et al. 2000). Ingested EHEC 0157:H7 remained inside the crop for 4 days and was detected in fecal drops (Sasaki et al. 2000).

Biology of Musca domestica

Oviposition

House flies are holometabolous insects with distinct egg, larval, pupal, and adult stages (West 1951, Sacca 1964). Within 1 day of becoming gravid, adult females seek decaying organic material and animal feces for their eggs (Krafsur 1985, Hogsette 1996, Graczyk et al. 2001). Female house flies may lay 5 to 6 batches of eggs, with each batch containing 75 to 150 eggs (Hogsette 1996, Graczyk et al. 2001).

Larval Development and Survival

House fly larvae develop in decaying organic material, including manure, and have three distinct larval stages (West 1951, McAlpine 1987). Larvae are milky white with a cylindrical shape that tapers anteriorly (McAlpine 1987). The posterior of M. domestica larvae is blunt and exhibits heavily scleritized posterior spiracles (McAlpine 1987).
Temperature of breeding sites directly affects the rate of larval development (Sacca 1964, Elvin and Krafsur 1984, Lysyk 1991b, Barnard and Geden 1993, Hogsette 1996). Developmental time from egg to adult may range from 6 days under optimal temperature conditions to 50 days (Barnard and Geden 1993). Haupt and Busvine (1968) reported that lower temperatures prolonged house-fly development and enhanced larval size. Sacca (1964) documented that 35 to 38°C was an optimal temperature range for larval development. Although higher temperature enhanced the rate of development, Barnard and Geden (1993) found that larval survival was highest between 17°C and 32°C.

Moisture levels within house fly breeding sites affect their survival. Animal manure moisture content ranging from 50 to 70% yielded significantly more flies than drier manure (Hulley 1986, Fatchurochim et al. 1989). Fatchurochim et al. (1989) reported a significant decline in house fly survival in manure containing less than 40% or more than 80% moisture. In addition, Hulley (1986) observed that manure with low moisture levels encouraged parasitism by pteromalid wasps. However, Hogsette (1996) found that some house flies could survive in manure containing less than 5% moisture, suggesting that house flies may survive under extreme conditions.

Survival of house fly larvae is also influenced by larval density within breeding sites. Haupt and Busvine (1968) and Barnard et al. (1998) observed inverse relationships between density and larval size and larval weight. Smaller larvae ultimately developed into smaller pupae and adults (Barnard et al. 1998). Larval mortality was significantly greater at high densities versus lower densities, while intermediate larval densities produce more viable progeny (Haupt and Busvine 1968, Bryant 1970). Bryant (1970) hypothesized that breeding sites conditioned by presence of larval densities regulated
oviposition rates, and thus egg densities in natural populations maintained an optimal density.

**Adult Behavior**

**Activity and longevity**

Behavior and activity of adult house flies changes with age. As male house flies age, wing function declined due to age and damage caused by mating attempts rendering them flightless within 12 days (Ragland and Sohal 1973). Mating activity, like flight activity, also declined with age.

Flight activity of *M. domestica* may be influenced by temperature and age. House flies are mobile between 14 and 40°C but peak flight activity occurs between 20 and 30°C (Tsutsumi 1968, Luvchiev et al. 1985). Flight activity significantly decreased above 35°C and activity ceased above and below 20°C, but high relative humidity contributed to a 2- to 3-fold increase in flight activity (Tsutsumi 1968, Buchan and Sohal 1981, Luvchiev et al. 1985). Since higher temperatures induced greater house fly activity, Buchan and Moreton (1981) observed that house fly lifespan significantly decreased at higher temperatures. They hypothesized that higher temperatures induced a higher metabolism, suggesting that the house fly rate of living also increased (Buchan and Moreton 1981, Buchan and Sohal 1981). Later experiments confirmed that life expectancy of both sexes significantly declined as temperature increased from 20 to 35°C (Fletcher et al. 1990, Lysyk 1991a).

Population density may also influence longevity of adult house flies. The life expectancy in the lab may range between 12 and 30 days for adult male house flies and between 11 and 44 days for adult females (Ragland and Sohal 1973, Fletcher et al. 1990).
Caged experiments using adult house flies showed an inverse relationship between adult life expectancy and population density (Rockstein et al. 1981). Susceptibility to high mortality associated with high density was greater for males than females (Haupt and Busvine 1968). Field experiments using artificial garbage dumps showed exponential growth of fly populations within 1 month of dumping the garbage and confirmed that as density increases, survivability decreases (Imai 1984, Krafsur 1985). Both adult males and females also showed an inverse relationship between life expectancy and mate access (Ragland and Sohal 1973).

Dietary restrictions may also influence life expectancy and activity of adult house flies. Rockstein et al. (1981) reported that protein-starved house flies of both sexes had a significantly lower life expectancy than protein-satiated flies. Adding sucrose for house flies reared on manure or powdered milk significantly increased the longevity of both sexes (Lysyk 1991a). Starved flies and flies fed on sugar-only diets were significantly more active than protein-satiated house flies (Tsutsumi 1968, Skovmand and Mourier 1986). Conversely, replete flies rested and showed a significantly higher frequency of regurgitation and resting behaviors (Tsutsumi 1968).

**Photoperiod**

House flies are diurnal insects whose activity is directly related to light intensity (Tsutsumi 1968, Sucharit and Tumrasvin 1981). Adult house flies entrained on a 12:12 (L:D) photoperiod showed resting behavior induced by lower light levels, and ceased flight activity at the onset of night even when the photoperiod was removed (Tsutsumi 1968). Although peak activity times ranged from 9AM to 4PM, continuous brightness ultimately suppressed the circadian rhythm of the house fly and complete darkness inhibited house fly activity (Tsutsumi 1968, Meyer et al. 1978, Semakula et al. 1989).
Dispersal

House flies are disease vectors capable of dispersing between 5 and 20 miles from their point of origin (Schoof and Silverly 1954b, Morris and Hansen 1966). Initial mark-recapture studies showed that flies dispersed randomly and approximately 50% of 150,000 released flies were captured within ½ mile from their initial release point (Schoof and Silverly 1954b). It was estimated that flies migrate 0.5 miles to 2.5 miles over a period of 1-5 days (Morris and Hansen 1966). However, a lack of available breeding sites encouraged flies to disperse up to ½ mile within 3 to 8 hours (Pickens et al. 1967). Although dispersal was random, Pickens et al. (1967) observed house flies were 2 to 3 times more likely to disperse from clean dairy farms versus unsanitary farms with multiple breeding sites.

Environmental factors such as wind may also affect dispersal (Morris and Hansen 1966). Strong down winds may aid in dispersal, but house flies have been observed flying upwind of breezes between 2 and 7 mph (Morris and Hansen 1966, Pickens et al. 1967).

In poultry and dairy units containing great abundance of animal manure, house flies dispersed approximately 50 meters (Lysyk and Axtell 1986, Hogsette et al. 1993). Rather than density-dependent mortality in field studies, evidence shows density-dependent dispersal toward better habitat (Imai 1984, Krafsur 1985). However, studies in poultry houses showed house fly distribution downwind was twice as great as upwind with dead-air zones containing the greatest abundance of adults (Geden et al. 1999).
Attractants for *Musca domestica*

**Chemical Attractants**

House flies respond to a wide variety of chemical or odorous attractants. In initial studies, excrement and decomposing organic material attracted significant numbers of house flies into containment traps (West 1951, Mulla et al. 1977). Food baits composed of sugar, molasses, putrified egg extracts, or chicken and rice were also successful attractants or served as a medium for insecticides (Pickens et al. 1973, Mulla et al. 1977, Pickens et al. 1994, Pickens 1995). Other studies using an odorous “dumpster recipe” caught significant numbers of house and stable flies, but such attractants may be limited to the outdoors (Pickens et al. 1975, Rutz et al. 1988).

The discovery and synthesis of the female sex pheromone (Z)-9-tricosene led to the development of muscalure and enhanced the efficacy of synthetic fly baits (Carlson and Beroza 1973, Carlson et al. 1974). Although (Z)-9-tricosene is produced by females, field trials showed significant attraction of both male and female house flies (Pickens et al. 1975, Rutz et al. 1988, Chapman et al. 1999). High concentration of (Z)-9-tricosene many act as an aggregation pheromone for both sexes of *M. domestica* (Chapman et al. 1998).

**Physical Attractants**

**Color**

House flies respond to a variety of environmental factors such as color, light quality, light reflectance, and color contrast (Hecht 1970). High color saturation of a surface combined with a strong contrast between that surface and its surrounding environment was thought to be more attractive to *M. domestica* than individual colors, however their response to individual colors seemed to change with temperature (Pickens...

The spectrum of reflected light, regardless of surface color, is more likely to induce landing response by house flies than the color of the surface (Bellingham 1995). Surfaces that reflected UV were more attractive to stable flies, while surfaces that absorbed UV were more attractive to horse flies (Agee et al. 1983, Hribar et al. 1991). Colorimetric studies with the face fly, *Musca autumnalis*, suggested that edge effects of baited traps could be enhanced by maximizing color contrast between traps and the surrounding environment (Pickens 1990).

**Surfaces**

Plane geometric patterns or shapes displayed on a surface may also enhance landing-response by *M. domestica*. Single shapes consisting of a large area and perimeter were significantly more attractive than a series of small shapes with small perimeters (Bellingham 1995). When house flies were presented with a series layout of squares, they significantly preferred outer squares and edges versus inner squares, with both sexes exhibiting significant preference toward shape corners (Bellingham 1995). There were no significant preferences by house flies toward symmetric versus asymmetric shapes, but simple shapes such as triangles and rectangles were significantly more attractive to house flies than complex shapes such as hexagons and octagons (Bellingham 1995). Bellingham (1995) and Hecht (1970) observed that house flies preferred to rest on rough dark surfaces such as red and black and preferred matte surfaces over glossy surfaces.
Overall, house flies preferred to rest on corners and edges of shapes or objects as well as narrow vertical objects hanging from ceiling, but they exhibited no significant preference toward horizontal or vertical stripes on a glue board (Keiding 1965, Bellingham 1995, Chapman et al. 1999). Later experiments on landing response demonstrated that house flies significantly preferred a clumped distribution of small black spots against a white background versus a regular distribution of spots (Chapman et al. 1998, Chapman et al. 1999). These studies suggested that visual cues resembling house-fly aggregations may also induce landing response (Chapman et al. 1999).

**Light**

The house fly eye is composed of different cells that are capable of gathering information about light quantity, quality, and polarization within the surrounding environment. Each facet of the compound eye of *M. domestica* contains three different kinds of photocells designated as R1 – R6, R7, and R8 (McCann and Arnett 1972). Each cell type provides specific visual information to the insect (McCann and Arnett 1972). Cells R1- R6 + R7 contain photopigments sensitive to 350-nm and 490-nm peaks with R8 containing photopigment sensitive to 490 only (McCann and Arnett 1972, Bellingham 1995). The dorsal rim area of the house fly eye detects polarization and polarization sensitivity is located in the R7 and R8 marginal cells (Philipsborn and Labhart 1990). Philipsborn and Labhart (1990) determined that house fly attraction to polarized light, especially in the UV range, is directly related to intensity of light. However, polarized UV did not always elicit phototactic response from house flies (Philipsborn and Labhart 1990). Polarization sensitivity is thought to provide information on spatial forms, motions, velocity, and contrast ratio in the fly’s environment and thus may help the fly track mates (McCann and Arnett 1972, Bellingham 1995).
The visible spectrum for *M. domestica* ranges 310 nm – 630 nm, with optimal attraction observed at 350 nm (Thimijan and Pickens 1973, Bellingham 1995). Electroretinogram studies have shown that the *M. domestica* eye is sensitive to UV light ranging from 340 nm to 370 nm and blue-green light ranging from 480 nm to 510 nm, but there is debate over how this sensitivity affects optomotor response of *M. domestica* (Goldsmith and Fernandez 1968, McCann and Arnett 1972, Thimijan and Pickens 1973). Goldsmith and Fernandez (1968) observed positive phototaxis by *M. domestica* towards UV light of 365 nm. McCann and Arnett (1972) observed that *M. domestica* is equally sensitive to 350 nm UV and 480 nm blue-green and concluded the house-fly eye contained separate photopigments for UV and blue-green light sensitivity. Similar studies with the face fly, *Musca autumnalis*, revealed a similar spectral range from 350 nm to 625 nm with peak sensitivities at 360 nm and 490 nm (Agee and Patterson 1983). Although blue-green sensitivity was relatively high, *M. domestica* attraction gradually decreased from 390 nm to 630 nm with no significant differences between male and female responses (Thimijan and Pickens 1973). Further studies have shown the house fly eye contains more UV-sensitive pigments in its dorsal region (Bellingham 1995). It was hypothesized that sensitivity to UV and blue green light may allow the fly to distinguish between ground and sky and detect predators or mates against the sky (Bellingham 1995).

Green and red light wavelengths may induce negative phototaxis in *M. domestica* (Green 1984). Green (1984) observed a direct relationship between attraction and intensity of near-UV 400-nm light and an inverse relationship between attraction and intensity of 550-nm (green) light. Straight UV elicited a significantly stronger phototactic response from *M. domestica* than green-UV suggesting that green-UV is less
attractive to house flies (Green 1984). *Musca domestica* were unable to distinguish red lights from green lights at various intensities (Green 1984). Bellingham (1995) observed that house flies detected red light (630 nm) but sensitivity to red was not attraction. Female house flies were more sensitive to red than males with the dorsal region of the eye containing red-sensitive pigments (Bellingham 1995).

**Control Using Attractants**

**Chemical Baits**

Insecticidal food baits or containment traps rely on synthetic attractants such as muscalure ((Z)-9-tricosene) to attract house flies and provide localized control of house fly populations. High doses of muscalure mixed with a sugar bait attracted significant numbers of house flies and seemed to promote significantly higher consumption of insecticide baits (Morgan et al. 1974, Lemke et al. 1990). Newer technology incorporating polymer beads impregnated with (Z)-9-tricosene significantly enhanced the long-term efficacy of sugar baits (Chapman et al. 1998). Physical traps combining muscalure with visual cues caught significantly more house flies than traps without muscalure (Mitchell et al. 1975, Mulla et al. 1979). However, baited trap catch decreased significantly at lower temperatures due to decreased volatilization of attractants (Pickens and Miller 1987).

**Physical Traps**

Baited jug traps made from plastic milk jugs, utilized (Z)-9-tricosene and indole to capture house flies breeding in poultry units (Burg and Axtell 1984). Although this design killed thousands of house flies, jug traps are primarily used for monitoring house fly populations (Burg and Axtell 1984, Stafford III et al. 1988).
Pickens and Miller (1987) reported that pyramid traps, utilizing glue boards or electric grids, were effective at intercepting dispersing house flies before they entered buildings (Pickens and Miller 1987). Subsequent trials with pyramid traps determined that vertical orientation of electric grids combined with chrome plating on electronic grids attracted and killed significantly more house flies (Pickens and Mills 1993). Replacing paint with white plastic increased UV reflectance, and thus attracted significantly more house flies toward pyramid traps (Pickens and Mills 1993).

Success of physical traps is largely dependent on their proximity to house fly breeding sites. Baited jug traps were most effective when hung 1 m above breeding and aggregation sites (Burg and Axtell 1984). Pyramid and baited traps were significantly more effective when placed within 3 m of breeding sites or sheltered from wind (Pickens and Miller 1987).

Insect Light Traps (ILT)

Insect light traps (ILTs) and electronic fly killers (EFKs) utilize UV light to lure *M. domestica* onto glue boards or kill them with electricity. Such devices are designed to exploit positive phototaxis in house flies and remove them from environments where insecticide applications are not an option. However, house fly response to UV traps varies due to a range of environmental and physiological factors.

House Fly Response to ILTs

Age of *M. domestica* may influence their response to light traps. Adult male and female house flies aged 7 d or older exhibited significantly slower response to UV light traps than flies aged 1 to 5 days (Pickens et al. 1969, Skovmand and Mourier 1986). Deimel and Kral (1992) observed that light sensitivity was related to age-dependent concentration of the photopigment xanthopsin in cells R1-R6. Age-dependent sensitivity
to light may have been influenced by visual experience gained within the first five days after adult emergence (Deimel and Kral 1992).

Hunger and nutrition also influenced searching activity of *M. domestica*, and thus light-trap catch may also be affected (Skovmand and Mourier 1986). House flies that were starved or sustained on a sugar and water diet were significantly more active than protein-satiated flies and thus starved flies responded to UV-light traps in significantly less time than protein-satiated flies (Skovmand and Mourier 1986). Bellingham (1995) suggested that food searching is non-oriented behavior motivated by the insect’s intrinsic nutritional needs. Once the insect satiates its hunger, then its behavior shifts toward mate location and environmental orientation (Bellingham 1995). This reasoning suggests that starved house flies are not necessarily more attracted to UV-light traps than satiated flies, but rather they have a higher probability of being caught simply because they are more active.

**Design and Location of ILTs**

Further attempts to enhance ILT performance focused on trap designs included increasing bulb wattage, manipulating trap colors, and adding reflective surfaces to the trap exterior. Increased bulb wattage provided a higher intensity of UV light, and thus yielded a significant increase in catch, but the use of black light blue (BLB) bulbs did not significantly increase attraction of house or stable flies when compared to standard black light (BL) bulbs (Pickens 1989b, Snell 1998). Pickens and Thimijan (1986) suggested a black-box trap offered greatest contrast to UV bulbs and caught significantly more flies. However, Snell (1998) found that black background was significantly less attractive than white background. Snell (1998) also suggested that grills created a significant distraction for house flies by providing them with a place to rest. Traps with greater grill lengths in
front of the UV bulbs caught significantly fewer flies compared with traps that had lower grill length (Snell 1998).

Location of light traps also plays an important role in their efficacy. Studies with electronic fly killers (EFKs) in poultry units demonstrated that traps located within 1m of the ground eliminated significantly more house flies than traps located 2m or higher (Driggers 1971). Subsequent studies with baited pheromone traps also reinforced the idea that ground-level traps within 3m of breeding sites were most efficient for eliminating flies (Mitchell et al. 1975, Pickens and Miller 1987). Skovmand and Mourier (1986) acknowledged that competing light sources as well as competing attractants distracted a significant number of house flies away from EFKs. They concluded UV-light traps, specifically EFKs, only provided marginal control in swine units because the abundance and production of house flies exceeded the traps’ ability to recruit flies (Skovmand and Mourier 1986).

**Competing Light Sources**

The urban environment presents house flies with location challenges as well as artificial light sources that may interfere with UV light traps. Lillie and Goddard (1987) demonstrated that multiple light traps significantly reduced house fly populations in restaurant kitchens. However, traps visible to the outdoors may attract flies into the structure (Lillie and Goddard 1987). Additionally, placement of light traps in dim areas enhanced the catch of house flies (Pickens and Thimijan 1986). Both Pickens and Thimijan (1986) and Shields (1989) implied that artificial cool-white fluorescent light adversely affected house-fly attraction to UV light traps, but neither study examined intensity or quality of artificial light.
Although greater light intensity may attract more flies, other factors such as flicker fusion and directionality of light may influence house fly response to a light source. Syms and Goodman (1987) discovered that light flicker created by alternating current (AC) was more attractive to house flies than light produced by direct current (DC). Ultra violet lights from AC sources with half the intensity of DC sources caught significantly more house flies (Syms and Goodman 1987, Shields 1989). Additionally, diffuse sources of light were significantly more attractive to *M. domestica* than directional light (Roberts et al. 1992). Neither Syms and Goodman (1987) nor Roberts et al. (1992) found any sex-related differences in house-fly response to AC-flicker or diffuse light sources.

The effects of competing light sources on vector monitoring programs utilizing light traps have been documented in the mosquito literature. Bowden (1973) acknowledged the inverse relationship between mosquito catch in light traps and intensity of background illumination from the moon. The intensity of moonlight gradually changed with each phase, light trap catches of mosquitoes adjusted accordingly (Bowden 1973). In Venezuela, illumination from a full moon reduced light trap catch abundance of *Anopheles* spp. by approximately one-half when compared to moonless trap nights (Rubio-Palis 1992). Similarly in India, Singh et al. (1996) documented significant reduction of *Anopheles* spp. caught by Center for Disease Control (CDC) light traps during a full moon phase compared with moonless trap nights. Although total catch was significantly lower, the parity rates of *Anopheles* spp. among samples remained the same regardless of the moon phase (Rubio-Palis 1992, Singh et al. 1996).

Bowden (1973) documented an inverse relationship between moonlight and trap catch for a variety of species of Coleoptera and Lepidoptera. Since light intensity
decreases at a rate equal to the inverse square of distance from its source, Bowden (1973) asserted that light traps exerted a region of influence unique to individual species and that insects outside of this region of influence would remain unaffected by the light trap. Therefore, modifications to light trap output or the intensity of competing illumination would alter a light trap’s area of influence (Bowden and Church 1973, Bowden 1982). In subsequent studies, Bowden (1982) estimated a minimum 12:1 ratio of background luminosity to trap luminosity was necessary to have an adverse effect on light trap performance. Increasing UV output from light traps may overcome some of these obstacles, but Bowden (1982) also noted a curvilinear relationship between total UV output and trap catch where significant increases in UV output resulted in marginal or no increases in trap catch (Bowden 1982). It is not known if the same relationship exists for house flies.

**Statement of Purpose**

The purpose of my research is to understand how factors in urban environments affect the catch efficacy of UV light traps used to manage house flies. I have designed a light-tunnel bioassay that presents house flies with both a UV light trap and a source of overhead competing light. Since location of UV traps may influence catch, the first research chapter (Chapter 2) establishes a baseline study of a light-tunnel bioassay that does not exhibit location bias. This bioassay was then used to determine effects of house fly age and gender on trap catch. The time to catch 50% of a population (CT_{50}) was estimated for house flies to determine the approximate time house flies responded to a UV trap. Information from these studies helped to eliminate any bias and determine the proper age range of house flies and length of time for the experiments.
Chapter 3 explores how intensity and spectrum of competing light sources affects house fly response to UV light traps. Light intensities sampled in five local restaurants and grocery stores provided a baseline range of intensity treatments for my experiments. For light quality experiments, house flies were presented with competing lights with spectral outputs ranging from UV light up through warm-white fluorescent.

Finally, Chapter 4 explores whether continuous exposure to artificial light induces habituation or attraction. If house flies habituate to light after continuous exposure, then I hypothesize that they would be less attracted to that source of light over time.
CHAPTER 2
ESTIMATES OF RESPONSE TIME BY HOUSE FLIES TOWARD UV LIGHT TRAPS USING LIGHT-TUNNEL BIOASSAY

Introduction

The house fly, *Musca domestica* L., is a synanthropic filth fly that breeds in garbage and animal waste (Schoof and Silverly 1954a, Greenberg 1973, Imai 1984, Graczyk et al. 2001). Larvae develop in manure, and the adults will feed on the larval substrate (Hogsette 1995). Growing populations of adult house flies are a nuisance to livestock, poultry, and humans, especially in urban centers adjacent to farming communities (Hogsette and Farkas 2000). In addition, house flies may also transmit enteric pathogens such as *Shigella* spp. and *Salmonella* spp., which they may acquire from their breeding sites and transmit to humans (Levine and Levine 1991, Graczyk et al. 2001).

The significance of house flies as disease vectors is enhanced by their capability of dispersing approximately 30 km from their point of origin (Schoof and Silverly 1954b, Morris and Hansen 1966). Subsequent studies estimated that flies dispersed an average of 1 to 4 km over a period of 1 to 5 d in search of suitable breeding sites within rural or urban areas (Morris and Hansen 1966, Hogsette and Farkas 2000).

As house flies cause problems in structures, light traps were developed as a tool to intercept house flies by attracting them to UV light and killing them with glue boards or high-voltage electricity (Pickens et al. 1969, Bowden 1982, Roberts et al. 1992). Prompt removal of house flies within hospitals, grocery stores, or restaurants is necessary to

Insect light traps are used to attract and catch house flies, but factors such as fly age or trap location within a building may limit trap catch. Dispersal from breeding sites into structures may take days, and as flies disperse, they age and may exhibit a significant decline in flight activity (Ragland and Sohal 1973). As house flies enter structures, light traps obscured from view may have little or no effect on a house-fly infestation and significant wind or air movement within a building may redirect house flies downwind away from potential light traps (Lillie and Goddard 1987, Rutz et al. 1988, Geden et al. 1999). Additionally, incident light from windows or overhead fixtures may also be an additional source of variability for light trap studies (Pickens and Thimijan 1986, Syms and Goodman 1987).

Although previous studies sought to understand variables that may affect light-trap performance, none have provided a standardized bioassay that eliminates variables such as background light, trap location, or air movement within a structure. Therefore, the first objective of this study was to develop and standardize a procedure that overcomes effects associated with light-trap placement. The second objective was to use the standardized procedure to examine the effects of fly age on light-trap catch efficacy and to examine house fly response time to insect light traps.

**Materials and Methods**

**Insects.** Two strains of *M. domestica* were used in this research; the USDA-CMAVE strain and the Horse-Teaching-Unit (HTU) strain, both from Gainesville, FL. Larvae from USDA-CMAVE strain were reared on USDA larval medium and held on a 12:12 (L: D) photoperiod (Hogsette 1992). Larvae from the HTU strain were reared on a
medium containing 3 liters wheat bran, 1.5 liters water, and 250 ml of Calf Manna® (Manna Pro Corp., St. Louis, MO) pellets. All stages of HTU strain were placed on a 12:12 (L: D) photoperiod at 26 ± 1°C and 51.03 ± 3.49% RH. Adult flies from both strains were provided granulated sugar, powdered milk, and water ad libitum and held on a 12:12 photoperiod (L:D) (Hogsette et al. 2002). Adult flies were held no longer than 7 days.

Before experimentation, adult flies between 2 and 5 d of age were aspirated from screen cages (25.4 by 53.3 by 26.7 cm) using a handheld vacuum with modified crevice tool. Aspirated flies were transferred into a refrigerator (~5°C) for 2 min to subdue activity. Flies were removed from the refrigerator and placed on a chilled aluminum tray, counted and sexed. Counted and sexed flies were placed into plastic cups (237 ml), lids were placed over the cups, then the flies were held at room temperature for approximately 30 min before being placed into experiments. All flies were handled with camel hair paint brushes and featherweight forceps.

Light tunnel design. The enclosed light-tunnel (152 by 20 dia. cm metal duct) consisted of a release cage attached to a galvanized aluminum light tunnel that terminated in a box enclosing a light trap (Fig. 2-1). The release cage (30 by 30 by 45 cm) was fitted with a sheet-metal bottom and aluminum window screen on the top, sides, and one end. Stockinette was fitted on the remaining end (30 by 30 cm) to allow access into the cage. Release cages were placed on a 10.4 cm-high platform to make them level with a light tunnel entrance. The light tunnel (152 by 20 dia. cm metal duct) was painted with one coat of primer and one coat of flat black paint, then allowed to cure for at least 3 d to eliminate paint fumes. A light-tunnel entrance (20 cm dia.) was cut into the box
enclosure (66 by 91 by 60 cm) which was constructed of corrugated cardboard. The 20 cm hole was centered horizontally on the 91-cm face and was 12.7 cm from ground level. Vents were cut in the top of the box enclosure (17.7 by 38.1 cm) to prevent buildup of heat from light traps. A piece of black organdy was glued over each vent to prevent flies from escaping. A piece of plywood (91 by 60 cm) was painted with white paint and placed inside the box enclosure opposite the light tunnel entrance. One UV light trap (Nova®, Whitmire Microgen Inc., St. Louis, MO) was mounted with four screws onto the white plywood inside the box enclosure. The trap was laterally centered and located directly opposite the light tunnel entrance. The trap utilized three 15-watt UV bulbs (Sylvania® Quantum™, Manchester, UK) as well as a horizontal (7.6 by 40.6 cm) and a vertical glue board (25.4 by 40.6 cm). Ultra-violet (UV) bulbs in traps had < 1000 h use. A workshop fixture containing two 40-watt Sylvania® cool-white fluorescent light bulbs was hung 8 cm above top of release cages to provide a source of background light that is common in urban environments. The distance of 8 cm above the cages was selected in order to establish intensity comparable with levels of competing light in urban environments.

**Procedure.** To perform an experiment, new glue boards were placed inside traps and all lights were turned on. One hundred sexed flies were released from a plastic cup (237 ml) into a release cage. Experiments commenced when stockinette on the release cages was unfurled and wrapped around the entrance of the light tunnel, allowing flies access to the UV light trap. At the end of each experiment, the release cages were sealed and removed, traps turned off, and glue boards collected. Flies not captured were
removed from the experimental set up prior to subsequent repetitions. Ambient
temperature for all experiments was approximately 29°C.

Quality and quantity of background light and ultraviolet light were measured at the
release-cage end of the light tunnel with a USB2000® Spectrometer (Ocean Optics®,
Dunedin, FL) (Fig.2-2). Absolute light quantity from cool-white fluorescent light and
UV-trap output was measured with a HOBO® Light Intensity logger (Onset®, Bourne,
MA).

Intensity data from light traps and overhead fluorescent light were analyzed at each
position to investigate significant differences among the light sources. Separate one-way
analyses of variance were run using light intensity as the response variable against trap
and position within building as main factors.

**Location dependent assay.** Experiments were conducted in two buildings (3 by 3
m) designated as Buildings A and B. All windows were covered with aluminum foil to
prevent external light from interfering with experiments. Two positions were identified
within each building and designated as positions a₁ and a₂ for Building A and positions
b₁ and b₂ for Building B. The four box enclosures opposite the release cages were
consecutively numbered and rotated among all four possible positions nested within the
two buildings. All repetitions used house flies from both strains. Four replications, each
with 100 adult house flies (50 M: 50 F) aged 2 to 5 d, were conducted per box and
position, for a total of eight replications per building. Assays were concluded after 4 h.

**Age dependent assay.** Pupae from both strains were removed from larval medium
and placed in separate screen cages (40.6 by 26.7 by 26.7 cm). Flies were allowed to
emerge for 24 h, then pupae were removed to ensure that all flies were of the same age.
Age of flies was based on the number of days after adult emergence from pupal cases. The assay was conducted with 100 flies (50 M: 50 F) aged 1, 3, 5, or 7 d placed in the release cage and left for 4 h. Flies on glue boards were counted sexed. Four replications per age were conducted.

**Time dependent assay.** Time treatments were started simultaneously when 100 adult flies (50 M: 50 F) were placed into each of four separate release cages for 1, 2, 4, or 8 h. Treatments were randomly assigned to each release cage *a priori* with four replications per time. At the end of each time period, the assigned release cage was closed, glue boards were collected, and the light trap was turned off.

**Statistical analysis.** For location studies, total numbers of male and female flies caught on glue boards were analyzed using a two-way nested analysis of variance with box enclosure and building as fixed factors with position nested within the building. Time and age studies were separately analyzed with one-way analysis of variance with time (h) or age (d) as fixed factors. Means separation for significant F-values was performed with a Student-Newman Keuls (SNK) test. A catch time for 50, 90, and 95% of house flies (CT$_{50}$) caught by UV light traps was estimated using probit analysis (SAS 2001).

**Results and Discussion**

**Location Dependent Assay.** Analyses of spectrometry data indicated there were no significant differences in light spectra and intensity from UV light traps (F=0.29; df = 3, 298; $P = 0.83$) or overhead cool-white fluorescent light among the four set ups (F=2.22; df = 3, 325; $P = 0.085$) (Figures 2-2 and 2-3). There were no significant differences in the numbers of house flies caught among the locations within buildings A and B ($F = 0.89$; df = 3, 13; $P = 0.46$) nor were any significant differences detected
among the four box enclosures (F=0.22; df = 3, 13; P = 0.87) (Table 2-1). On average, 65 adult house flies were caught among all positions over a period of 4 h, thus the different positions within and among buildings A and B did not significantly influence house fly response to light traps (Table 2-1).

In previous studies, the effects of location bias on catch efficacy of UV light traps depend largely on environmental factors unique to each site. Lillie and Goddard (1987) found that catch efficacy in urban environments varied due to trap location relative to other sources of light such as windows or doors that might lure flies away from a UV light trap. Light quality and intensity were standardized in this research among all positions within our buildings. Rutz et al. (1988) suggested that UV light traps are most effective when placed in close proximity to house-fly breeding sites and areas of high activity, but they did not define any specific distance. In the current study, house flies were released 2.66 m from the UV light traps. Furthermore, Geden et al. (1999) reported that in closed poultry units, house flies significantly preferred dead-air spaces versus direct air currents. By providing an enclosed light-tunnel design, the current study eliminated air movement between the release cage and the light trap. Thus, results showed that removing variability of location, trap distance, background light intensity, and air movement, assured that the house flies responded to light traps in consistent manner.

**Age-dependent assay.** Significantly greater numbers of male house flies aged 1, 3, and 5 d were caught by UV light traps than 7-day old male house flies (Table 2-2). One possible reason for this decline is that as male house flies age, wing function declined due to damage caused by mating attempts (Ragland and Sohal 1973). Within our colonies, I
observed mating attempts among flies of all ages but noticed significant wing damage among males aged 7 d or older.

There was no significant difference in response among all age groups of female house flies toward UV light traps (Table 2-2). The nutritional state of 7 d old female house flies may have influenced their activity levels. All house flies had access to protein (powdered milk), carbohydrates (granulated sugar), and water within 1 h prior to experiments. Tsutsumi (1968) reported that protein-satiated house flies rest more and fly less than protein-starved house flies. However, if protein-satiated adult females were mated, then their flight activity may have increased as they searched for a site for oviposition (Tsutsumi 1968, Skovmand and Mourier 1986). If females were gravid and looking for a dark place to oviposit, then one would expect to see a decline in their response towards light traps.

When results of both sexes were combined, the overall response to UV light traps by adult house flies significantly decreased at 7 d of age because of the reduction in the number of males captured (Table 2-2). Results agree with previous studies indicating that significantly fewer house flies aged > 5 d were caught in UV light traps (Pickens et al. 1969). As house flies age, their sensitivity to light decreases due to deterioration of photopigments within cells R1-R6 of the fly eye (Deimel and Kral 1992). These results confirmed that house flies aged ≤ 5 d are most likely to be caught in UV light traps.

**Time-dependent assay.** The cumulative mean number of male and female house flies caught by UV light traps significantly increased over a time period of 1 to 8 h (Table 2-3). Although total trap catch by 8 h was significantly greater than catch at 4, 2, or 1 h,
some house flies did not respond to the light trap and remained in the release cage throughout the duration of the experiment (Table 2-3).

Male house flies were caught inside the light traps within an estimated $CT_{50}$ of 1.56 h (99 min) (Table 2-4). The $CT_{90}$ and $CT_{95}$ estimated catch time for males at 5.03 h (301.8 min) and 7.01 h (420.6 min), respectively (Table 2-4). Female house flies were caught inside the light traps within an estimated $CT_{50}$ of 1.90 h (114 min) (Table 2-4). The $CT_{90}$ and $CT_{95}$ estimated catch time for females at 7.02 h (421.2 min) and 10.17 h (610.2 min) respectively (Table 2-4).

Probit analysis estimated the $CT_{50}$ for total house fly response toward an UV light trap at approximately 1.72 h (103.2 min) (Table 2-4). The $CT_{90}$ and $CT_{95}$ estimate for total house fly catch was 6.01 h (360.6 min) and 8.57 h (514.2 min), respectively (Table 2-4). There was no significant difference between male and female response time as evident by overlapping 95% confidence intervals for $CT_{50}$, $CT_{90}$, and $CT_{95}$ (Table 2-4).

Skovmand and Mourier (1986), who also conducted a series of light-trap experiments inside an enclosed chamber, concluded that male house flies responded to UV light traps in significantly less time than females. The $CT_{50}$ estimate of 99 min (1.56 h) for male response was similar to their estimated $LT_{50}$ of 100 min (Skovmand and Mourier 1986). However, the $CT_{50}$ estimates for females of 114 min was slower than the 52 min reported by Skovmand and Mourier (1986), and there were no significant differences in response time between males and females (Table 2-4). During these studies, I observed some house flies remained inside the release cage throughout the duration of the test and thus, reduced our estimates for house fly response to light traps.
In conclusion, the light-tunnel bioassay enabled us to standardize conditions for age and time studies by reducing variability associated with air movement, trap location, trap distance, and background light. House flies that were \( \leq 5 \) d old exhibited significantly greater attraction toward UV light traps than older flies. Estimates of CT\(_{50}\) by house flies toward UV traps ranged from 99 to 114 min for males and females, respectively, with no significant difference in response between the sexes.
Table 2-1. Effect of building, position within building, and box enclosure on the number of house flies caught in UV light traps (50 M: 50 F per repetition).

<table>
<thead>
<tr>
<th>Building</th>
<th>Mean ± SE</th>
<th>Position</th>
<th>Mean ± SE</th>
<th>Box enclosure</th>
<th>Mean ± SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>63.56 ± 2.41</td>
<td>a₁</td>
<td>63.75 ± 3.79</td>
<td>1</td>
<td>65.62 ± 3.56</td>
</tr>
<tr>
<td></td>
<td>68.00 ± 2.58</td>
<td>a₂</td>
<td>64.87 ± 3.63</td>
<td>2</td>
<td>65.62 ± 3.71</td>
</tr>
<tr>
<td></td>
<td></td>
<td>b₁</td>
<td>68.37 ± 3.72</td>
<td>3</td>
<td>68.00 ± 3.51</td>
</tr>
<tr>
<td></td>
<td></td>
<td>b₂</td>
<td>68.12 ± 3.71</td>
<td>4</td>
<td>65.87 ± 4.25</td>
</tr>
</tbody>
</table>

Means within a column followed by the same letter are not significantly different (P = 0.05, Student Newman-Keuls test [SAS Institute, 2001]).
Table 2-2. Influence of age and sex on number of house flies caught in UV light traps (50 M: 50 F per repetition)

<table>
<thead>
<tr>
<th>Gender</th>
<th>1 Mean ± SE</th>
<th>3 Mean ± SE</th>
<th>5 Mean ± SE</th>
<th>7 Mean ± SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>40.75 ± 2.33a</td>
<td>38.25 ± 1.47a</td>
<td>45.5 ± 1.97a</td>
<td>22.75 ± 3.22b</td>
</tr>
<tr>
<td>Female</td>
<td>46.25 ± 2.18a</td>
<td>48.25 ± 3.75a</td>
<td>42.5 ± 2.52a</td>
<td>40.00 ± 1.08a</td>
</tr>
<tr>
<td>Total</td>
<td>87.0 ± 3.21a</td>
<td>87.25 ± 3.37a</td>
<td>88.0 ± 2.67a</td>
<td>62.6 ± 4.21b</td>
</tr>
</tbody>
</table>

Means within a row followed by the same letter are not significantly different (P = 0.05, Student Newman-Keuls test [SAS Institute, 2001]).
Table 2-3. Cumulative house-fly catch in UV light traps over time (50 M: 50 F per repetition)

<table>
<thead>
<tr>
<th>Time (h)</th>
<th>Gender</th>
<th>Mean ± SE</th>
<th>Mean ± SE</th>
<th>Mean ± SE</th>
<th>Mean ± SE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
<td>15.2 ± 1.88a</td>
<td>31.0 ± 1.92b</td>
<td>37.0 ± 2.24b</td>
<td>48.0 ± 1.3c</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>12.6 ± 1.03a</td>
<td>26.8 ± 3.76b</td>
<td>32.8 ± 3.92c</td>
<td>45.8 ± 1.46d</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>27.8 ± 2.6a</td>
<td>57.8 ± 5.32b</td>
<td>71.8 ± 6.58c</td>
<td>93.8 ± 2.03d</td>
</tr>
</tbody>
</table>

Means within a row followed by the same letter are not significantly different (P = 0.05, Student Newman-Keuls test [SAS Institute, 2001]).
Table 2-4. Estimated time (h) to catch of adult house flies by UV light traps using Probit analysis

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>Reps</th>
<th>Slope ± SE</th>
<th>CT$_{50}$</th>
<th>95% C. I.</th>
<th>CT$_{90}$</th>
<th>95% C. I.</th>
<th>CT$_{95}$</th>
<th>95% C. I.</th>
<th>$X^2$</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>50</td>
<td>5</td>
<td>2.52 ± 0.18</td>
<td>1.56</td>
<td>1.40-1.72</td>
<td>5.03</td>
<td>4.29-6.15</td>
<td>7.01</td>
<td>5.78-9.01</td>
<td>0.34</td>
<td>0.557</td>
</tr>
<tr>
<td>Female</td>
<td>50</td>
<td>5</td>
<td>2.26 ± 0.15</td>
<td>1.90</td>
<td>1.71-2.11</td>
<td>7.02</td>
<td>5.88-8.80</td>
<td>10.17</td>
<td>8.19-13.43</td>
<td>0.52</td>
<td>0.467</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>5</td>
<td>2.35 ± 0.11</td>
<td>1.72</td>
<td>0.59-1.84</td>
<td>6.01</td>
<td>5.31-6.95</td>
<td>8.57</td>
<td>7.37-10.26</td>
<td>1.03</td>
<td>0.307</td>
</tr>
</tbody>
</table>
Figure 2-1. Light tunnel design illustrating release cage (30 by 30 by 45 cm) (foreground), overhead light source (101.6 cm), light tunnel (152 by 20 cm), and box enclosure (66 by 91 by 60 cm) containing light trap.
Figure 2-2. Intensity (lumens/m²) of UV-light trap with relative intensity of light by wavelength.

Intensity ± SE of UV light traps
1.33 ± 0.048 lumens/m²
Figure 2-3. Intensity (lumens/m²) of cool-white fluorescent light with relative intensity of light by wavelength

Intensity ± SE of cool white fluorescent light
54.87 ± 0.92 lumens/m²
CHAPTER 3
INFLUENCES OF QUALITY AND INTENSITY OF BACKGROUND LIGHT ON
HOUSE FLY RESPONSE TO LIGHT TRAPS

Introduction

*Musca domestica* L. is a synanthropic insect that breeds in animal waste, dumpsters, and garbage (Morris and Hansen 1966, Imai 1984). They are known to transmit pathogens such as *Salmonella* spp., *Shigella* spp., *Campylobacter* spp., and enterohemorrhagic *E. coli* from their breeding sites to open food markets, hospitals, slaughter houses, and animal farms (Levine and Levine 1991, Iwasa et al. 1999, Graczyk et al. 2001). Because house flies are potential disease vectors, their control in urban environments is necessary to prevent food contamination.

A variety of devices have been developed to attract and kill house flies in agricultural and urban areas. Baited traps containing molasses, sugar, decomposing biomass, or animal excrement have been used to lure house flies into a catch basin from which they can not escape (West 1951, Pickens et al. 1973, Mulla et al. 1977). Pyramid traps utilizing glue boards or electrocution grids were effective at intercepting house flies before they entered buildings (Pickens and Miller 1987). But although these traps may be effective in outdoor settings, their odorous baits and visibility prohibit their use indoors. Additionally, trapped flies must be emptied and baits must be replenished to maintain trap efficacy.

Insect light traps utilizing ultraviolet (UV) light ranging from 340-370 nm were developed after physiological and behavior studies demonstrated that house flies
exhibited positive phototaxis toward UV-emitting light sources (Goldsmith and Fernandez 1968, McCann and Arnett 1972). Light traps utilizing glue boards to subdue attracted flies are a common management tool in indoor settings (Lillie and Goddard 1987).

Ultraviolet light traps for indoor use are an alternative to chemicals, but some factors in urban environments that may limit trap success. As house flies disperse within a building, they may encounter competing sources of light originating from windows or overhead light fixtures which may interfere with trap catch (Pickens and Thimijan 1986). Previous studies demonstrated that increasing UV output of light traps significantly enhanced catch efficacy of house flies, but they did not take into account light-trap performance relative to competing light sources in the urban environment (Pickens and Thimijan 1986, Snell 1998). Therefore, the first objective of this study was to examine competing light intensities in public settings where light traps would most likely be used, then corroborate those data with light-intensity levels in experiments to measure effects of competing light intensity on house-fly response to UV light traps. The second objective was to present house flies with competing light sources with different spectral outputs and quantify their response to UV light traps.

**Materials and Methods**

**Insects.** The Horse-Teaching-Unit (HTU) strain of *M. domestica* from Gainesville, FL, was used in this research. Larvae from the HTU strain were reared on a medium containing 3 liters wheat bran, 1.5 liters water, and 250 ml of Calf Manna® (Manna Pro Corp., St. Louis, MO) pellets. All stages of HTU strain were placed on a 12:12 (L: D) photoperiod at 26 ± 1°C and 51.03 ± 3.49% RH. Adult flies from both strains were
provided granulated sugar, powdered milk, and water *ad libitum* and held on a 12:12 photoperiod (L:D) (Hogsette et al. 2002). Adult flies were held no longer than 7 days.

Before experimentation, adult flies were aspirated from screen cages (25.4 by 53.3 by 26.7 cm) using a handheld vacuum with modified crevice tool. Aspirated flies were transferred into a refrigerator (~5°C) for 2 min to subdue activity. Flies were removed from the refrigerator and placed on a chilled aluminum tray, counted and sexed. Counted and sexed flies were placed into plastic cups (237 ml), clear plastic lids were placed over the cups, then the flies were held at room temperature for approximately 30 min before being placed into experiments. All flies were handled with camel hair paint brushes and featherweight forceps.

**Light tunnel design.** Enclosed light-tunnel design consists of a release cage attached to a galvanized aluminum light tunnel that terminates in a box enclosing a light trap (Fig. 2-1). The release cage (30 by 30 by 45 cm) was fitted with a sheet-metal bottom and aluminum window screen on the top, sides, and one end. Stockinette was fitted on the remaining end (30 by 30 cm) to allow access into the cage. Release cages were placed on a 10.4 cm-high platform to make them level with a light tunnel entrance. The light tunnel (152 by 20 dia. cm metal duct) was painted with one coat of primer and one coat of flat black paint, then allowed to cure for at least 3 d to eliminate paint fumes. A light-tunnel entrance (20 cm dia.) was cut into the box enclosure (66 by 91 by 60 cm) that was constructed of corrugated cardboard. The 20 cm hole was centered horizontally on the 91-cm face, and was 12.7 cm from ground level. Vents were cut in the top of the box enclosure (17.7 by 38.1 cm) to prevent buildup of heat from light traps. A piece of black organdy was glued over each vent to prevent flies from escaping. A piece of
plywood (91 by 60 cm) was painted with white paint and placed inside the box enclosure opposite the light tunnel entrance. One UV light trap (Nova®, Whitmire Microgen Inc., St. Louis, MO) was mounted with four screws onto the white plywood inside the box enclosure. The trap was laterally centered and located directly opposite the light tunnel entrance. The trap utilized three 15-watt UV bulbs (Sylvania® Quantum™, Manchester, UK) as well as a horizontal (7.6 by 40.6 cm) and a vertical glue board (25.4 by 40.6 cm). Ultra-violet (UV) bulbs in traps had < 1000 h use. A workshop fixture containing two 40-watt Sylvania® cool-white fluorescent light bulbs was hung 8 cm above release cages to provide a source of background light that is a common light source in urban environments. The distance of 8 cm above the cages was selected in order to establish intensity comparable with levels of competing light in urban environments.

**Procedure.** To perform an experiment, new glue boards were placed inside traps and all lights were turned on. One hundred sexed flies were released from a plastic cup (237 ml) into a release cage. Experiments commenced when stockinette on the release cages was unfurled and wrapped around the entrance of the light tunnel, allowing flies access to the UV light trap. After 4 h, experiments were shut down and at the end of each experiment, the release cages were sealed and removed, traps were turned off, and glue boards were collected. The time period of 4 h was selected because preliminary results showed between 90 and 100% of flies within dark controls were caught inside UV light traps after 4 h. Flies not captured were removed from the experimental set up prior to subsequent repetitions. Ambient temperature for all experiments was approximately 27 to 29°C. All repetitions contained 100 adult house flies (50 M: 50 F) between 2 and 5 d of age.
Light intensity survey of restaurants and grocery stores. A HOBO® Light Intensity logger (Onset®, Bourne, MA) was used to measure light intensity inside five restaurants and/or grocery stores. The logger was held 1.3 m from the ground with its light sensor facing the ceiling and the researcher carried the logger throughout the establishment in this fashion. Data were collected at 5-s intervals until a minimum of 100 points were collected at each establishment. Direct sunlight was avoided at all locations because its high intensity may influence average measurements of artificial light.

Impact of competing light intensity on trap catch. Four intensity levels of competing light were set up based upon the results of the field survey. Two workshop light fixtures, each containing two fluorescent 40-watt light bulbs, were suspended directly above the release cages. A range of 1 to 4 40-watt bulbs were illuminated and provided light intensities ranging from 27 to 125 lumens/m². Three replications were conducted per intensity level.

Impact of competing light spectra on trap catch. Four types of fluorescent light bulbs were presented to house flies as a source of overhead competing light. The bulb models and types were as follows: Sylvania® Warm White (F40T12/WW), Sylvania® Cool White (F40T12/CW), Sylvania® Daylight (F40T12/DX), and Sylvania® Blacklight (F40T12/350BL). Two fluorescent workshop light fixtures, each capable of holding two 40-watt light bulbs, were suspended directly above the release cages. Three 40-watt bulbs of each model were placed inside the fixtures and illuminated during experiments. Four replications were conducted per treatment.

Spectral analyses and relative intensity of all treatments were measured using a USB2000® spectrometer (Ocean Optics®, Dunedin, FL). Light intensity for all treatment
outputs was measured with a HOBO® Light Intensity logger (Onset®, Bourne, MA). Since measurements of light intensity by HOBO® Light Intensity logger (350 to 700 nm) represented a proportion of total spectrum measured by the USB2000® spectrometer (200 to 820 nm), total light intensity was estimated using the following formulae where \( \Sigma_{\text{Total spectrum units}} \) represents relative light intensity measured by the USB2000® spectrometer and \( \Sigma_{\text{Measured light units}} \) represents relative light intensity perceived by the HOBO® Light Intensity logger. Measured light represents the light intensity (lumens/m\(^2\)) recorded by the HOBO® Light Intensity logger and units measured represent intensity counts per nanometer tabulated by USB2000® spectrometer using OOIBase32 software (Ocean Optics®, Dunedin, FL).

\[
\Sigma_{\text{Measured light units}} = \frac{\Sigma_{\text{Total spectrum units}}}{\text{Proportion Total light output (\%)}
\]

\[
\text{Measured light (lumens/m}^2) = \frac{\Sigma_{\text{Total spectrum units}}}{\text{Proportion Total light output (\%)} \times \text{Estimate Total light output (lumens/m}^2)\]

Once the Estimate Total light output (lumens/m\(^2\)) was calculated, the intensity levels of UV (350 to 370 nm) and blue-green light (480 to 510 nm) were also calculated. The \( \Sigma_{\text{UV light units}} \) and \( \Sigma_{\text{Blue-green light units}} \) represent intensity counts per nanometer tabulated by USB2000® spectrometer using OOIBase32 software (Ocean Optics®, Dunedin, FL).

\[
\Sigma_{\text{UV light units}} = \frac{\Sigma_{\text{Total spectrum units}}}{\text{Proportion UV light output (\%)}
\]

\[
\text{Proportion UV light output (\%)} \times \text{Estimate Total light output (lumens/m}^2) = \text{Estimate UV light output (lumens/m}^2)
\]

\[
\Sigma_{\text{Blue-green light units}}
\]
\[ \sum \text{Total spectrum units} = \text{Proportion Blue-green light output} \times \text{Proportion Total light output} \times \text{Estimate Total light output (lumens/m}^2) \]

\[ = \text{Estimate Blue-green light output (lumens/m}^2) \]

**Statistical analysis.** Because all four treatments for the light-intensity experiments and light-quality experiments could not be conducted simultaneously, both experiments were set up using a two-way balanced incomplete block design. Treatment pairs were randomly assigned *a priori* for each trial day until all possible treatment combinations were met (SAS 2001). A dark control was run concurrently with each experiment. For each dark control, house flies were placed into a release cage and presented with an illuminated Whitmire Nova® trap at the end of the light tunnel without a competing light source placed overhead. Means were separated with a Student Newman-Keuls test. Regression analysis was conducted on data from light-intensity experiments to examine the relationship between trap catch and intensity of blue-green light. Another regression analysis was conducted on light-quality experiments to examine the relationship between trap catch and UV intensity.

**Results and Discussion**

**Light intensity survey.** Results of light-intensity survey at area restaurants and grocery stores showed intensity of artificial and natural light sources ranged from approximately 27 to 91 lumens/m\(^2\) (Table 3-1). Light intensity of treatments within laboratory bioassays was within the range of field results (Table 3-2).

**Impact of competing light intensity on trap catch.** The number of males caught in UV traps significantly decreased when intensity of the competing light exceeded 91.46 lumens/m\(^2\) when compared with dark controls \((F= 9.63; \text{df} = 4, 50; P < 0.0001)\) (Table 3-3). The number of females caught declined significantly when intensity of competing
light exceeded 51.43 lumens/m² (F= 18.17; df = 4, 50; P < 0.0001) (Table 3-3). When the data were combined, the overall results showed total catch in UV light traps decreased significantly as the intensity of competing light source increased (F = 39.46; df = 4, 50; P < 0.0001) (Table 3-3).

As overall competing light intensity was increased, spectral analyses showed the relative intensity of a blue-green light increased 5x from the lowest to highest treatment (Table 3-4; Figs. 3-1 to 3-4). Regression analysis showed a significant correlation between increases in blue-green light and decreases in trap catch (Fig. 3-5). Blue-green light ranging between 480nm and 510nm constituted approximately 13% of total light emitted from fluorescent fixtures in all treatments (Table 3-4; Figs. 3-1 to 3-4). Both Pickens and Thimijan (1986) and Shields (1989) have suggested that artificial cool-white fluorescent light adversely affected house-fly attraction to UV light traps, but neither study measured spectral output nor measured their effects on house-fly behavior. The blue-green light emitted by cool-white fluorescent bulbs in the current study corresponded directly with the blue-green sensitivity of the house-fly eye demonstrated in previous studies (Figs. 3-1 to 3-4) (McCann and Arnett 1972, Bellingham 1995). These results suggest that relatively high intensities of competing light containing blue-green wavelengths may distract house flies from relatively low intensities of ultraviolet emitted from light traps.

Approximately 1 to 2% of light emitted from cool-white fluorescent treatments consisted of UV ranging between 350 to 370 nm (Table 3-4; Figs 3-1 to 3-4). Spectral analyses showed the UV emission from fluorescent treatments exceeded the UV originating from light traps by almost 4x when four bulbs were used (Table 3-4; Figs. 3-1
However, the spectrum of the UV consisted of a narrow spike that peaked at 365 nm contrasted with the broad-based UV from the light traps ranging from 310 to 399 nm with a peak at 350 nm (Table 3-4; Figs. 3-1 to 3-4). Previous studies have demonstrated that higher intensity of UV output significantly increased house fly catch within light traps (Pickens and Thimijan 1986, Pickens 1989b, Snell 1998). But if house flies in this study were simply responding to UV intensity, then one would expect to find a greater number of flies remaining inside the release cage at the conclusion of the experiments.

Bowden and Church’s studies (1973) documented an inverse relationship between moonlight and trap catch for multiple species of beetles and moths. Since light intensity decreases at a rate equal to the inverse square of distance from its source, Bowden and Church (1973) asserted that light traps exerted a region of influence unique to individual species. Insects outside of this region would remain unaffected by the trap, and modifications to light-trap output or intensity of competing illumination would alter the size of this region (Bowden and Church 1973). If the same concept applies to house flies, then competing fluorescent light originating from multiple overhead light fixtures reduces the region of influence of UV light traps by saturating the environment with full-spectrum fluorescent light. Subsequently, Bowden (1982) estimated that a minimum 12:1 ratio of background light to trap light was necessary to have an adverse effect on light trap performance. This ratio may hold for some species of Coleoptera or Lepidoptera, but my lab studies found that background light intensity must be approximately 25 times greater than light intensity from a trap to have a significant adverse effect on house fly response (Bowden 1982). Although this may seem high, intensity of competing light in urban environments can meet or exceed light levels...
reported in this study (Table 3-1). In addition, as the intensity of UV light diminishes over distance, the survey study showed that average light intensity from competing sources remained relatively constant within each restaurant or grocery store (Table 3-1).

**Impact of competing light spectra on trap catch.** Results of the light quality studies showed significantly fewer male \( F = 21.28; \text{df} = 4, 64; P < 0.0001 \) and female house flies \( F = 37.85; \text{df} = 4, 64; P < 0.0001 \) were caught among all treatments when compared against a dark control (Table 3-5). When the data were pooled together, overall trap catch among all treatments was also significantly lower than the dark control \( F = 56.60; \text{df} = 4, 64; P < 0.0001 \), but significantly fewer flies were caught in light traps when competing light consisted of black light versus daylight, cool-white, and warm-white fluorescent (Tables 3-5 and 3-6; Figs. 3-5 to 3-8).

Blacklight bulbs emitted the lowest intensity of blue-green light while day light bulbs emitted the highest intensity of blue-green (Table 3-6; Figs. 3-6 to 3-9). For this study, regression analysis showed a significant correlation between increases in UV and decreases in trap catch (Fig. 3-10). Intensity of UV emitted from Blacklight treatments was approximately 10x greater than UV intensity from daylight, cool white, and warm white treatments (Table 3-6; Figs. 3-6 to 3-9). In addition, the intensity of UV output from all treatments exceeded UV emitted from light traps (Table 3-6; Figs. 3-6 to 3-9). Yet the spectrum of the UV produced by daylight, cool white, and warm white fluorescent bulbs consisted of a narrow spike peaking at 365 nm contrasted with blacklight treatments and insect light traps which emitted broad-based UV ranging from 310 – 399 nm and peaking at 350 nm (Table 3-6; Figs. 3-6 to 3-9).
The *M. domestica* eye is sensitive to UV light ranging from 340 nm to 370 nm and blue-green light ranging from 480 nm to 510 nm, but there is debate over how this sensitivity affects a house fly’s optomotor response (Goldsmith and Fernandez 1968, McCann and Arnett 1972, Thimijan and Pickens 1973, Green 1984). Although blue-green sensitivity was relatively high, phototactic response by male and female *M. domestica* gradually declined as light spectra approached 630 nm (Thimijan and Pickens 1973). Results from our light quality experiments were consistent with previous literature indicating that house flies exhibited a stronger response toward UV versus blue-green wavelengths (Pickens 1989a).

In conclusion, the results of our lab study showed a significant decrease in response of male and female house flies toward UV light traps as the intensity of competing fluorescent light was increased. When house flies were presented four different types of competing light, their response towards UV light traps was significantly lower when competing light sources contained broad-based UV versus blue-green light.
Table 3-1. Light intensity (lumens/m²) measured within five local restaurants (R) and grocery stores (G)

<table>
<thead>
<tr>
<th>Location</th>
<th>n</th>
<th>Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (G)</td>
<td>100</td>
<td>27.33 ± 1.59</td>
</tr>
<tr>
<td>B (R)</td>
<td>100</td>
<td>28.29 ± 0.37</td>
</tr>
<tr>
<td>C (R)</td>
<td>100</td>
<td>50.67 ± 0.80</td>
</tr>
<tr>
<td>D (G)</td>
<td>100</td>
<td>61.43 ± 2.42</td>
</tr>
<tr>
<td>E (R)</td>
<td>100</td>
<td>91.24 ± 1.28</td>
</tr>
</tbody>
</table>

Table 3-2. Light intensity (lumens/m²) of four intensity treatments of cool-white fluorescent light measured 45 cm from light source

<table>
<thead>
<tr>
<th>Number of bulbs</th>
<th>Total wattage</th>
<th>Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>40 W</td>
<td>27.43</td>
</tr>
<tr>
<td>2</td>
<td>80 W</td>
<td>51.21</td>
</tr>
<tr>
<td>3</td>
<td>120 W</td>
<td>91.46</td>
</tr>
<tr>
<td>4</td>
<td>160 W</td>
<td>125.67</td>
</tr>
</tbody>
</table>
Table 3-3. Effect of intensity of cool-white fluorescent light as a competing light source on number of adult house flies (mean ± SE) caught in UV light traps (50 M: 50 F per repetition)

<table>
<thead>
<tr>
<th>Gender</th>
<th>Dark control</th>
<th>Light intensity</th>
<th>Light intensity</th>
<th>Light intensity</th>
<th>Light intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>27.43</td>
<td>51.43</td>
<td>91.46</td>
<td>125.67</td>
</tr>
<tr>
<td>Male</td>
<td>45.25 ± 0.51a</td>
<td>42.66 ± 1.31ab</td>
<td>41.88 ± 1.16ab</td>
<td>40.00 ± 1.49bc</td>
<td>37.00 ± 1.15c</td>
</tr>
<tr>
<td>Female</td>
<td>47.00 ± 0.58a</td>
<td>45.00 ± 1.28ab</td>
<td>42.66 ± 0.70bc</td>
<td>40.55 ± 1.37cd</td>
<td>38.22 ± 1.35d</td>
</tr>
<tr>
<td>Total</td>
<td>92.29 ± 0.85a</td>
<td>87.66 ± 1.45b</td>
<td>84.55 ± 1.20b</td>
<td>80.55 ± 0.97c</td>
<td>75.22 ± 0.92d</td>
</tr>
</tbody>
</table>

Means within a row with the same letter are not significantly different (P=0.05; Student-Newman Keuls [SAS Institute, 2001])
Table 3-4. Estimated intensity (lumens/m²) of total spectral output, blue-green output, and ultraviolet output emitted from competing light sources and light traps used in light quantity experiments

<table>
<thead>
<tr>
<th>Number of Cool white bulbs</th>
<th>Estimated total light intensity (480-510nm)</th>
<th>Blue-green output (350-370nm)</th>
<th>UV output (350-370nm) + UV output</th>
<th>Blue-green output</th>
<th>Total Trap Catch</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>33.01</td>
<td>3.36</td>
<td>0.70</td>
<td>4.06</td>
<td>87.66 ± 1.45</td>
</tr>
<tr>
<td>2</td>
<td>59.23</td>
<td>6.46</td>
<td>1.03</td>
<td>7.49</td>
<td>84.55 ± 1.20</td>
</tr>
<tr>
<td>3</td>
<td>104.22</td>
<td>11.85</td>
<td>1.26</td>
<td>13.11</td>
<td>80.55 ± 0.97</td>
</tr>
<tr>
<td>4</td>
<td>140.60</td>
<td>16.66</td>
<td>1.59</td>
<td>18.65</td>
<td>75.22 ± 0.92</td>
</tr>
<tr>
<td>UV Trap</td>
<td>1.95</td>
<td>0.06</td>
<td>0.44</td>
<td>0.50</td>
<td>--</td>
</tr>
</tbody>
</table>
Table 3-5. Effect of competing light quality on mean number (± SE) of adult house flies caught in UV light traps (50 M: 50 F per repetition)

<table>
<thead>
<tr>
<th>Gender</th>
<th>Dark control</th>
<th>Warm white</th>
<th>Cool white</th>
<th>Daylight</th>
<th>Blacklight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>45.91 ± 0.61a</td>
<td>40.25 ± 1.15b</td>
<td>39.16 ± 1.86b</td>
<td>39.66 ± 0.91b</td>
<td>30.83 ± 1.91c</td>
</tr>
<tr>
<td>Female</td>
<td>46.71 ± 0.63a</td>
<td>35.66 ± 2.14b</td>
<td>33.16 ± 2.61b</td>
<td>34.50 ± 1.21b</td>
<td>21.08 ± 2.13c</td>
</tr>
<tr>
<td>Total</td>
<td>92.79 ± 0.81a</td>
<td>75.91 ± 2.72b</td>
<td>73.41 ± 1.87b</td>
<td>74.16 ± 1.63b</td>
<td>52.08 ± 3.84c</td>
</tr>
</tbody>
</table>

Means within a row with the same letter are not significantly different (P=0.05; Student-Newman Keuls [SAS Institute, 2001])
Table 3-6. Estimated intensity (lumens/m$^2$) of total spectral output, blue-green output, and ultraviolet output emitted from competing light sources and light traps used in light quality experiments

<table>
<thead>
<tr>
<th>Competing light spectrum</th>
<th>Estimated total light intensity</th>
<th>Blue-green output (480-510nm)</th>
<th>UV output (350-370nm)</th>
<th>Blue-green + UV output</th>
<th>Total Trap Catch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blacklight</td>
<td>73.84</td>
<td>2.02</td>
<td>15.79</td>
<td>17.81</td>
<td>52.08 ± 3.84</td>
</tr>
<tr>
<td>Day Light</td>
<td>76.61</td>
<td>11.94</td>
<td>1.27</td>
<td>13.21</td>
<td>74.16 ± 1.63</td>
</tr>
<tr>
<td>Cool White</td>
<td>84.80</td>
<td>9.68</td>
<td>1.30</td>
<td>9.98</td>
<td>73.41 ± 1.87</td>
</tr>
<tr>
<td>Warm White</td>
<td>89.62</td>
<td>10.57</td>
<td>1.73</td>
<td>12.30</td>
<td>75.91 ± 2.72</td>
</tr>
<tr>
<td>UV Trap</td>
<td>1.95</td>
<td>0.06</td>
<td>0.44</td>
<td>0.50</td>
<td>--</td>
</tr>
</tbody>
</table>
Figure 3-1. Spectral analysis and mean intensity (lumens/m²) of 1 Sylvania® Cool White fluorescent bulb measured at 61 cm from source. Arrow highlights blue-green peak between 480 and 510 nm.
Figure 3-2. Spectral analysis and mean intensity (lumens/m²) of 2 Sylvania® Cool White fluorescent bulbs measured at 61 cm from source. Arrow highlights blue-green peak between 480 and 510 nm.
Figure 3-3. Spectral analysis and mean intensity (lumens/m²) of 3 Sylvania® Cool White fluorescent bulbs measured at 61 cm from source. Arrow highlights blue-green peak between 480 and 510 nm.
Figure 3-4. Spectral analysis and mean intensity (lumens/m²) of 4 Sylvania® Cool White fluorescent bulbs measured at 61 cm from source. Arrow highlights blue-green peak between 480 and 510 nm.
**Figure 3-5.** Regression analysis showing relationship between trap catch and intensity (lumens/m²) of blue-green light

\[ y = -0.9108x + 90.723 \]

\[ R^2 = 0.9933 \]

\[
\begin{array}{c}
\text{Trap catch} \\
74 \quad 76 \quad 78 \quad 80 \quad 82 \quad 84 \quad 86 \quad 88 \quad 90
\end{array}
\]

\[
\begin{array}{c}
\text{Intensity of Blue-green light (480-510nm)} \\
0 \quad 2 \quad 4 \quad 6 \quad 8 \quad 10 \quad 12 \quad 14 \quad 16 \quad 18
\end{array}
\]
Figure 3-6. Spectral analysis and mean intensity (lumens/m$^2$) of Sylvania® Blacklight bulbs measured at 61 cm from source. Arrow highlights UV peak between 340 and 370 nm.
Figure 3-7. Spectral analysis and mean intensity (lumens/m²) of Sylvania® Daylight fluorescent bulbs measured at 61 cm from source. Arrow highlights blue-green peak between 480 and 510 nm.
Figure 3-8. Spectral analysis and mean intensity (lumens/m²) of Sylvania® Cool White fluorescent light measured at 61 cm from source. Arrow highlights blue-green peak between 480 and 510 nm.
Figure 3-9. Spectral analysis and mean intensity (lumens/m²) of Sylvania® Warm White fluorescent light measured at 61 cm from source. Arrow highlights blue-green peak between 480 and 510 nm.
Figure 3-10. Regression analysis showing relationship between trap catch and intensity (lumens/m²) of blue-green light.

\[ y = -1.5558x + 76.704 \]

\[ R^2 = 0.9854 \]
CHAPTER 4
LIGHT TRAP HABITUATION STUDY

Introduction

The house fly *Musca domestica* (Diptera: Muscidae) is a nuisance in agricultural and urban environments (Cosse and Baker 1996, Moon 2002, Hogsette 2003). High populations of house flies can cause economic losses in livestock, and dispersing house flies are pestiferous in residential and commercial areas (Hogsette and Farkas 2000). House flies breed in animal waste, dumpsters, and garbage and have been implicated as mechanical vectors of enteric diseases such as *Salmonella* spp. and *Shigella* spp. among animals and humans (Imai 1984, Graczyk et al. 2001, Mian et al. 2002).

In urban areas, UV light traps are used to manage house flies. Insect light traps that utilize ultra-violet light were developed as an alternative to insecticide applications. As house flies enter structures they are exposed to artificial light through time, but it is unknown whether continued exposure to artificial light influences their sensitivity to UV light traps. If house flies habituate to background light in their surrounding environment, then they may be more inclined or disinclined to fly towards a UV-light trap. Therefore, the objective of this study was to determine if previous experience with fluorescent or UV light influences house fly response to UV light traps.

**Materials and Methods**

**Insects.** The Horse-Teaching Unit (HTU) strain of house fly, *M. domestica*, from Gainesville, FL, was used for all studies presented here. Larvae were reared on a medium containing 3 liters wheat bran, 1.5 liters water, and 250 ml of Calf Manna®
(Manna Pro Corp., St. Louis, MO) pellets. All stages of HTU strain were placed on a 12:12 (L: D) photoperiod at 26°C ± 1°C and ~55% RH. Adult flies from both strains were provided granulated sugar, powdered milk, and water ad libitum and held on a 12:12 photoperiod (L:D) (Hogsette 1992, Hogsette et al. 2002). Adult flies were held no longer than 7 d.

Prior to experimentation, adult flies were aspirated from screen cages using a handheld vacuum with modified crevice tool to aspirate adult flies. Aspirated flies were transferred into a refrigerator (~5°C) for 2 min to subdue activity. Subdued flies were removed from the refrigerator and placed on a chilled aluminum tray, then counted and sexed. Counted and sexed flies were placed into deli cups (237 ml) and held at room temperature for approximately 30 min. All flies were handled with camel hair paintbrushes and featherweight forceps to prevent damage.

**Light tunnel design.** Enclosed light-tunnel design consisted of a release cage attached to a galvanized aluminum light tunnel that terminates in a box enclosing a light trap (Fig. 1). The release cage (30 by 30 by 45 cm) was fitted with a sheet-metal bottom and aluminum window screen on the top, sides, and one end. Stockinette was fitted on the remaining end (30 by 30 cm) to allow access into the cage. Release cages were placed on a 10.4 cm platform to make them level with a light tunnel entrance. The light tunnel (152 by 20 dia. cm metal duct) was primed and painted with one coat of primer and one coat of flat black paint, then allowed to cure for at least 3 d to eliminate paint fumes. A light-tunnel entrance (20 cm dia.) was cut into the box enclosure (66 by 91 by 60 cm) which was constructed of corrugated cardboard. The 20 cm hole was centered horizontally on 91 cm face, and it was 12.7 cm from ground level. Vents were cut into
the top of the box enclosure (17.7 by 38.1 cm) to prevent buildup of heat from light traps. A piece of black organdy was glued over each vent to prevent flies from escaping. A piece of plywood (91 by 60 cm) was painted with white paint and placed inside the box enclosure opposite the light tunnel entrance. One UV light trap (Nova®, Whitmire Microgen Inc., St. Louis, MO) was mounted with four screws onto the white plywood inside the box enclosure. The trap was laterally centered and located directly opposite the light tunnel entrance. The trap utilized three 15-watt UV bulbs (Sylvania® Quantum™, Manchester, UK) as well as horizontal (7.6 by 40.6 cm) and vertical (25.4 by 40.6 cm) glue boards. Ultra-violet light bulbs in light traps had less than 1000 h use. A workshop light containing two 40-watt Sylvania® cool-white fluorescent light bulbs was hung 8 cm above release cages to provide a source of background light that is a common light source in urban environments.

**Procedure.** All experiments were conducted inside two buildings (3 by 3 m); each building held two light tunnels. New glue boards were placed inside traps and all lights were turned on. One hundred counted and sexed adult flies were released from a plastic cup (237 ml) into a release cage. Experiments commenced when stockinette on the release cages was unfurled and wrapped around the entrance of the light tunnel, allowing access to the UV light trap. At the end of each experiment the release cages were sealed and removed, traps were turned off and glue boards were collected. Flies not captured were removed from the experimental set up prior to subsequent repetitions. Ambient temperature for all experiments was 29°C.

Quality and quantity of light were recorded at the release-cage end of the light tunnel (Fig. 2). Spectral analyses and relative light intensities were measured using a
USB2000® Spectrometer (Ocean Optics®, Dunedin, FL). Absolute light quantity for
cool-white fluorescent light output and UV-trap output was measured with a HOBO®
Light Intensity logger (Onset®, Bourne, MA).

Light habituation treatments. All house flies in primary lab colonies were reared
on a 12:12 (L:D) photoperiod using 4 40-watt GE® Wide Spectrum Plant and Aquarium
bulbs (GE F40PL/AQ) at intensity of 10.28 ± 2.38 lumens/m². Prior to habituation
experiments, house fly pupae were separated from primary lab colonies, placed in a
screen holding cage (30 by 17.5 by 30 cm) and stored in a separate rearing room.
Holding cages were covered on top and three sides with aluminum foil to prevent
overhead light from entering the cages. The side of the holding cage (30 by 17.5 cm) that
was not covered by aluminum foil was placed 12 cm away directly in front of a light
fixture. Light fixtures provided either cool-white fluorescent light from four 15W
Sylvania® Cool White bulbs or UV light from four 15W Sylvania® Quantum™ Blacklight
bulbs. Cool white fluorescent light was selected for this treatment because it is a
common source of indoor lighting. Emerging adult house flies in holding cages were
reared on a 12:12 photoperiod (L:D) of either cool-white fluorescent light at intensity of
34.11 ± 0.54 lumens/m² or black light bulbs at intensity of 15.88 ± 0.39 lumens/m² for 2
to 3 d prior to experiments. All house flies were provided with powdered milk,
granulated sugar, and water ad libitum.

Statistical analysis. Since both treatments for the habituation experiments could
not be conducted simultaneously, this study was set up using a two-way balanced
incomplete block design. Treatment pairs were randomly assigned a priori for each trial
day until all possible treatment combinations were met (SAS 2001). A dark control was
run concurrently with each repetition. For each dark control, house flies were placed into a release cage and presented with an illuminated light trap at the end of the light tunnel without a competing light source placed overhead. The house flies used in all controls were selected from the original laboratory colonies. A Whitmire Nova light trap was used in all dark controls.

**Results and Discussion**

Although all treatments caught significantly fewer house flies than the dark control, there was no significant difference in the response to UV light traps among house flies reared on UV light, cool-white light, versus the plant and aquarium light used in the laboratory ($F = 11.47; \text{df} = 3, 21; P < 0.0001$) (Table 4-1). Rearing house flies on blacklight or cool-white fluorescent did not influence their response to UV light traps (Table 4-1; Figs. 4-1 to 4-3). If house flies did habituate to blacklight, then we would have expected a significantly lower response to UV light traps. Conversely, if they habituated to cool-white fluorescent, then we would have expected to see a significant increase in their response to UV light traps.

Fukushi (1976) demonstrated that house flies could discriminate among narrow ranges of light wavelengths when specific wavelengths were associated with sugar water. Although this experiment of classical conditioning was not directly related with my experiment, it does illustrate that visual experience with specific wavelengths of light can influence house fly behavior (Fukushi 1976).

Pickens et al. (1969) speculated that adult house flies exposed to UV-light traps for at least 12 h exhibited a significantly greater response towards light traps compared with adult house flies that did not have previous visual experience with UV. This result would suggest that house flies developed increased sensitivity to UV, not habituation (Pickens et
al. 1969). But our results showed that prior exposure to UV light did not significantly increase or decrease catch efficacy of light traps (Table 4-1). Subsequent studies on visual sensitivity of house flies showed that dark-reared flies responded to significantly lower intensity levels of light than house flies reared on a 12:12 (L:D) photoperiod (Deimel and Kral 1992). Thus, Deimel and Kral (1992) determined that fly vision developed within the initial 1-5 d after adult emergence and suggested that visual experience within this time frame may influence the flies’ sensitivity to light. However, their research did not compare sensitivity across different light spectra, but rather light intensity needed to stimulate the optic nerve (Deimel and Kral 1992). These results show that the spectrum of light presented to house flies during this developmental period did not influence house fly response to overhead or UV light when placed in a bioassay that provides them with a choice of light spectra.
Table 4-1. Mean number of adult house flies caught in UV light traps after being pre-conditioned under different light conditions.

<table>
<thead>
<tr>
<th>Gender</th>
<th>Control</th>
<th>Wide spectrum</th>
<th>Black light</th>
<th>Cool white</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>45.22 ± 0.51a</td>
<td>40.66 ± 1.31b</td>
<td>36.33 ±1.16b</td>
<td>36.66 ± 1.49b</td>
</tr>
<tr>
<td>Female</td>
<td>44.00 ± 0.58a</td>
<td>41.16 ± 1.28b</td>
<td>40.33 ±0.70b</td>
<td>40.50 ± 1.37b</td>
</tr>
<tr>
<td>Total</td>
<td>89.22 ± 0.85a</td>
<td>81.82 ± 2.45b</td>
<td>76.66 ±1.20b</td>
<td>77.16 ± 1.97b</td>
</tr>
</tbody>
</table>

Means within a row with the same letter are not significantly different (P=0.05; Student-Neuman Keuls [SAS Institute, 2001]).
Figure 4-1. Spectral analysis and mean intensity of GE® Plant & Aquarium fluorescent light used in house fly rearing room. Mean light intensity presented in lumens/m².
Figure 4-2. Spectral analysis and mean intensity of Sylvania® Blacklight used to rear treatment house flies. Mean light intensity presented in lumens/m².
Figure 4-3. Spectral analysis and mean intensity of Sylvania® Cool White fluorescent light used to rear treatment house flies. Mean light intensity presented in lumens/m².
CHAPTER 5
SUMMARY AND CONCLUSIONS

The main purpose of this research was to investigate factors in the urban environment that inhibit the catch efficacy of UV light traps used to manage the house fly, *Musca domestica*, in urban environments. To do this, the first priority was to develop a standard bioassay that eliminated or reduced position effects associated with light-trap placement that influence results. Initial studies with a light tunnel bioassay demonstrated there were no significant position effects detected among two research buildings, four positions, or box enclosures which enclosed the light traps. In addition, the light-tunnel bioassay minimized air movement and standardized trap location, trap distance, and background light for future experiments.

The first portion of this research investigated the effect of house fly age on its response to UV light traps. House flies that were 5 d and younger exhibited significantly greater attraction toward UV light traps than older flies. The second part of the first research chapter used probit analysis to estimate response time of house flies to UV traps. A catch time for 50% of house flies (CT$_{50}$) within UV traps was estimated from 99 – 114 min for males and females. The estimated CT$_{50}$ for total house fly response toward an UV light trap was approximately 1.72 h (103.2 min). The CT$_{90}$ and CT$_{95}$ estimates for total house fly catch were 6.01 h (360.6 min) and 8.57 h (514.2 min) respectively. There was no significant difference between male and female response time as evident by overlapping 95% confidence intervals for CT$_{50}$, CT$_{90}$, and CT$_{95}$. 
For the second portion of this research, house flies were presented various intensity levels of cool-white fluorescent light in order to determine whether intensity of non-UV competing light sources influenced house fly attraction to UV light traps. Intensity levels in experiments correlated with preliminary surveys of overhead and natural light within local grocery stores and restaurants where light traps are commonly used. Results showed that the number of males caught in UV traps significantly decreased when intensity of the competing light exceeded 91.43 lumens / m². Significant declines in catch of females occurred at a lower intensity when the competing light exceeded 51.43 lumens / m². When the data were combined, the overall results showed total catch in UV light traps decreased significantly as the intensity of competing light source increased. These results demonstrated a significant decrease in response of male and female house flies toward UV light traps as the intensity of competing fluorescent light was increased.

House flies were also presented with four different types of competing light which covered a broad spectral range from UV to red (700 nm) which is beyond the house fly’s visual perception. Again, house fly response toward UV light traps significantly declined when a source of competing light was introduced. However, house fly response towards UV light traps was significantly lower when background light contained broad-based UV versus background light containing blue-green light and no UV.

Finally, the third portion of this research investigated whether or not house flies habituated to light quality within their surrounding environment. House flies from current colonies were compared against house flies reared on black light and cool-white fluorescent light. The results of habituation experiments showed that all treatments caught significantly fewer house flies than the dark control. However, there was no
significant difference in the response to UV light traps among house flies reared on UV light, cool-white fluorescent light, and grow-lights which are used in the rearing rooms. The spectrum of light used in rearing did not significantly influence house fly response to UV light traps. These results also suggest that previous experience to different kinds of light does not influence house fly response to light traps.
Figure A-1. Diagram of buildings, positions, and bioassay layout at USDA
APPENDIX B
SAS PROGRAMS USED FOR DATA ANALYSIS

SAS programs for Chapter 2

/Analysis of variance for study standardizing the bioassay/
/ ‘Position’ is nested within ‘Building’/

Proc glm data = work.fly;
Class building (position);
Model male fem total = building (position);
Means building (position) / snk;
Run;

/Analysis of variance for age study/

Proc glm data = work.fly;
Class age;
Model male fem total = age;
Means age / snk;
Run;

/Probit analyses for Time study/

/Probit analysis for total number of flies caught on glue boards/

Proc probit data = work.fly inversecl log10 lackfit;
Class gbtot;
Model time/n = hrs /;
Run;
/N = 500/

/Probit analysis for adult male house flies caught on glue boards/
Proc probit data = work.fly inversecl log10 lackfit;
Class male;
Model time/n1 = hrs /;
Run;
/N1 = 250/
/Probit analysis for adult female house flies caught on glue boards/
Proc probit data = work.fly inversecl log10 lackfit;
Class female;
Model time/n1 = hrs /
Run;
/N1 = 250/

/Analysis of variance comparing light output of four UV light traps/
Proc sort data = work.light;
By trap;

Proc glm data = work.light;
Class trap;
Model intensity = trap;
Means trap / SNK;
Run;

/Analysis of variance comparing overhead cool-white fluorescent light measured at four independent positions/
Proc sort data = work.light;
By position;

Proc glm data = work.light;
Class position;
Model intensity = position;
Means position / SNK;
Run;
SAS programs for Chapter 3

Proc sort data = work.fly; by day treatmnt;

Proc univariate data = work.fly;
Class treatmnt;
Var total male fem;

Run;

/ Balanced Incomplete Block Design (BIBD); Two-way analysis of variance (BIBD) of light intensity data /

Proc sort data = work.fly; by day treatmnt;

Proc glm data = work.fly;
Class day treatmnt;
Model male fem total = day treatmnt;
Means treatmnt / snk;
Lsmeans treatmnt / pdiff;

Proc glm data = work.fly;
Class day treatmnt;
Model armale arfem artotal = day treatmnt;
Means treatmnt / snk;
Lsmeans treatmnt / pdiff;

Proc sort data = work.sex;
by treatmnt;

Proc glm data = work.sex;
by treatmnt;

Class sex;
Model resp aresp = sex;
Means sex / snk;

Proc sort data = work.sex; by sex;

Proc glm data = work.sex; by sex;
Class treatmnt;
Model resp aresp = treatmnt;
Means treatmnt / snk;

Run;
/Proc univariate for light quality data/

Proc sort data = work.fly; by day treatmnt;

Proc univariate data = work.fly;
Class treatmnt;
Var total male fem;

/Balanced Incomplete Block Design; Two-way analysis of variance (BIBD) of light quality data/

Proc sort data = work.fly; by day treatmnt;

Proc glm data = work.fly;
Class day treatmnt;
Model male fem total = day treatmnt;
Means treatmnt / snk;
Lsmeans treatmnt / pdiff;

Proc glm data = work.fly;
Class day treatmnt;
Model armale arfem artotal = rep treatmnt;
Means treatmnt / snk;
Lsmeans treatmnt / pdiff;

Proc sort data = work.sex;
by treatmnt;

Proc glm data = work.sex;
by treatmnt;

Class sex;
Model resp aresp = sex;
Means sex / snk;

Proc sort data = work.sex; by sex;

Proc glm data = work.sex; by sex;
Class treatmnt;
Model resp aresp = treatmnt;
Means treatmnt / snk;

Run;
SAS Programs for Chapter 4

Proc sort data = work.fly;
by day treatmnt;

Proc univariate data = work.fly;
Class treatmnt;
Var total male fem;

Run;

/ Balanced Incomplete Block Design (BIBD); Two-way analysis of variance (BIBD) for
light habituation data/

Proc sort data = work.fly;
by day treatmnt;

Proc glm data = work.fly;
Class rep treatmnt;
Model male fem total = day treatmnt;
Means treatmnt / snk;
Lsmeans treatmnt / pdiff;

Proc glm data = work.fly;
Class day treatmnt;
Model armale arfem artotal = day treatmnt;
Means treatmnt / snk;
Lsmeans treatmnt / pdiff;

Proc sort data = work.sex;
by treatmnt;

Proc glm data = work.sex; by treatmnt;
Class sex;
Model resp aresp = sex;
Means sex / snk;

Proc sort data = work.sex;
by sex;

Proc glm data = work.sex; by sex;
Class treatmnt;
Model resp aresp = treatmnt;
Means treatmnt / snk;

Run;
APPENDIX C
SPECTROMETRY MEASUREMENTS FOR LIGHT TRAPS AND BACKGROUND LIGHT

Figure C-1. Spectral analysis and mean light intensity of Whitmire Nova trap 1 at Position a₁

Position a₁
Mean light intensity
1.33 ± 0.15 lumens/m²
Figure C-2. Spectral analysis and mean light intensity of Whitmire Nova trap 2 at Position a₂

Position a₂

Mean light intensity
1.34 ± 0.09 lumens/m²
Figure C-3. Spectral analysis and mean light intensity of Whitmire Nova trap 3 at Position b₁

Position b₁
Mean light intensity
1.35 ± 0.14 lumens/m²
Figure C-4. Spectral analysis and mean light intensity of Whitmire Nova trap 4 at Position b$_2$

Position b$_2$

Mean light intensity
$1.33 \pm 0.17$ lumens/m$^2$
Figure C-5. Spectral analysis and mean intensity of overhead cool-white fluorescent light at Position a₁

Position a₁

55.92 lumens/m²
Figure C-6. Spectral analysis and mean intensity overhead cool-white fluorescent light at Position a₂

Position a₂

53.67 lumens/m²
Figure C-7. Spectral analysis and mean intensity overhead cool-white fluorescent light at Position $b_1$

Position $b_1$

54.88 lumens/m$^2$
Figure C-8. Spectral analysis and mean intensity overhead cool-white fluorescent light at Position b₂

Position b₂

55.01 lumens/m²
APPENDIX D
REARING CONDITIONS FOR CONLONIES OF MUSCA DOMESTICA

Mean Temperature
26.41 ± 0.19 °C

Figure D-1. Temperature (C°) of rearing room for adult Musca domestica recorded by HOBO Temp & RH data logger
Figure D-2. Relative Humidity (%) of rearing room for adult *Musca domestica* recorded by HOBO Temp & RH data logger

Mean RH
59.94 ± 0.78%
Figure D-3. Light intensity (lumens/m²) of rearing room for adult *Musca domestica* recorded by HOBO Light Intensity data logger. Graph illustrates 12:12 (L:D) photoperiod

Mean Intensity
10.28 ± 2.38 lumens/m²
Figure D-4. Temperature (C°) of rearing room for *Musca domestica* larvae recorded by HOBO Temp & RH data logger

Mean Temperature
26.19 ± 0.42 C°
Figure D-5. Relative Humidity (%) of rearing room for *Musca domestica* larvae recorded by HOBO Temp & RH data logger

Mean RH
51.03 ± 3.49%
Figure D-6. Light intensity (lumens/m²) of rearing room for *Musca domestica* larvae recorded by HOBO Light Intensity data logger. Graph illustrates 12:12 (L:D) photoperiod.
LIST OF REFERENCES


Pickens, L. G. 1989a. Factors affecting the distance of scatter of house flies (Diptera: Muscidae) from electrocuting traps. J. Econ. Entomol. 82: 149-151.


BIOGRAPHICAL SKETCH

Matthew D. Aubuchon, son of David and Claire Aubuchon, was born February 7, 1974, in St. Louis, Missouri. He graduated from St. Louis University High School in 1992. After high school, he attended Indiana University and graduated with honors in 1996 after completing the requirements for the degree of Bachelor of Science with a major in environmental science and public policy. During his senior year of college, Matt moved to Washington, D.C., for an internship at the nonprofit organization Center for Policy Alternatives. During the summers of 1995 through 1997, Matt acquired his aquatic-applicator license and worked on over 100 lakes throughout Indiana and Michigan abating invasive species of aquatic plants. Matt moved to Auburn in Fall of 1997 and worked as a laboratory technician for the Auburn University Department of Entomology. In winter, 1998, he was accepted into the graduate entomology program at Auburn University, where he pursued his master’s degree under the guidance of Dr. Gary Mullen. After finishing his M.S. in August, 2001, Matt promptly moved to Gainesville, FL, to pursue his Ph.D. at the Entomology and Nematology Department under the guidance of Dr. Phil Koehler. On April 23, 2005, Matt was married to Amanda Kathleen Chambliss in St. Augustine, FL.