Bat Activity at Woodland/Farmland Interfaces in Central Delaware

Kelly A. Wolcott[1,2,*] and Kevina Vulinec[1]

Abstract - Bats vary their activity with different features of habitat, resource availability, predation risk, and other factors. Agricultural fields may provide an abundance of insect prey, but are also risky habitats due to their exposure. How bats use mixed landscapes is important information for biologists, as increasing development affects the amount of suitable habitat and impacts bat populations in the region. Using acoustic recording, we monitored relative bat activity in open areas and edges of the woodland/farmland interface of agricultural fields in Kent County, DE. We examined bat activity among different sites, in openings versus edges, among crop types, relative to nearby forest fragment size and shape, and under different weather conditions. Bat activity was significantly higher along edges than in the open in the agricultural fields for passes/night, but we found no differences among crop types or sites and no interaction effects. We also found no effect of size or amount of edge of a fragment on bat activity. We found significant negative correlations between passes and temperature and wind speed, and significant positive correlations between passes and relative humidity and barometric pressure. Bats use agricultural areas for foraging, and the woodland interfaces along these fields are important for bat activity. This study provides data that may help engender conservation practices, such as retention of forested edges and maintenance of tree lines, and perhaps crop selection and pest control management, in the region's farming community.

Introduction

Bats use small woodlands and riparian-farmland interfaces as foraging or commuting corridors (Geggie and Fenton 1985, Hein et al. 2009, Sparks et al. 2005). However, these landscapes are rapidly vanishing as development accelerates—a particular problem on the Delmarva Peninsula, where both forests and farmland are rapidly being converted to residential developments (DNREC Wildlife 2006, Weber et al. 2006). As the amount of suitable habitat decreases, bat populations may decline. Agricultural pests, particularly moths and beetles, are common in the region (Kee 2007, Tipping et al. 2005), and bats contribute to their control (Jones et al. 2009). Bats' efficiency as predators has increasingly been studied, and with the population declines due to White-nose Syndrome, details of their roles in ecosystem integrity may emerge (Federico et al. 2008, Lacki et al. 2007).

Vertical landscape features, such as trees and hedgerows, often increase insect populations (Lewis and Dibley 1970) and are important as flyways and foraging sites for bats (Verboom and Spoelstra 1999). Trees on farms contribute to the diversity of wildlife, and a decrease in this habitat feature is expected to lead to a significant decline in bats and other wildlife (Fischer et al. 2010). Vaughan et al. (1997) advocated

[1]Department of Agriculture and Natural Resources, Delaware State University, 1200 North DuPont Highway, Dover, DE 19901. [2]Current address - Federal Energy Regulatory Commission, Washington, DC 20426. [*]Corresponding author - kelly.wolcott@ferc.gov.

that land management plans for agricultural areas, woodlands, and freshwater areas should include attention to variation in vegetation structure to allow for diversity in insects and other fauna, including bats. Most studies on agricultural fields have focused on how habitat type (i.e., water sources, arable land, hedgerows, tree spacing, etc.) influences bat activity (Downs and Racey 2006; Federico et al. 2008; Law and Chidel 2006; Wickramasinghe et al. 2003, 2004), yet little research has explored crop type and bat activity. Current studies of bats in croplands have generally looked only at one crop type (Davy et al. 2007) or at the difference between conventional and organic farms (Federico et al. 2008, Gibson et al. 2007).

Development has recently intensified in Delaware (Liu and Lynch 2011); thus, we wanted to understand the current activity levels of the local bat populations in relation to increasing development. We were particularly interested in monitoring farmlands, which are often the site of the only remaining forested lands in the region (Allen 2009). Delaware lost at least 50,000 acres of farmland and connected woodland between 1997 and 2002, with consequent negative impacts on wildlife (Mix and Hurley 2008). Several factors may affect bat activity on farmlands, including habitat type, vegetation and forested area present, pesticide usage, and prey abundance (Wickramasinghe et al. 2004). To examine if bats are using both farmland and forest-agriculture edges (riparian and woodlands), we investigated bat activity using ultrasonic acoustic detectors at woodland/farmland interfaces in four sites in central Delaware. Our objectives were to determine if: 1) bat activity varied among selected agricultural sites within the central Delaware region, 2) bat activity differed between open agricultural field versus field edge, 3) bat activity differed among crop types, 4) there was a difference in bat activity among surrounding forest fragments by size and amount of edge, and 5) bat activity in our area was affected by weather variables (temperature, relative humidity, barometric pressure, and wind speed).

Field-site Description

Our study areas were located at (1) the Bombay Hook National Wildlife Refuge (BHNWR), (2) Smyrna Outreach and Research Center (SORC), (3) Woodland Beach Wildlife Area (WBWA), and (4) the Little Creek Wildlife Area (LCWA) (Fig. 1). All sites were near Dover, DE. We chose agricultural areas within each study site that were geographically accessible, were bordered on at least one side by forest, and were similar in surrounding vegetation associations. We limited our sampling to forest edges and open areas, as Delaware has limited large tracts of forest (and interior forest) due to agricultural and suburban development (Jones et al. 2009). The forested strips we used were embedded in a matrix of agricultural land and suburban and urban developments (Fig. 1). All sites except SORC had protected marshes nearby.

BHNWR is 6475 hectares, of which 728 hectares are devoted to agriculture (USFWS 2004). The refuge participates in cooperative farming of corn and soybean and some winter wheat and clover. Winter wheat is planted as a cover crop, and clover fields serve as feeding areas for wildlife. SORC is owned by Delaware State University (DSU) and is 78 hectares in size (R. Barczewski, Delaware State University, Dover, DE, pers. comm.). Over the course of this research, three crops were grown on a rotational basis: soybean, corn, and hay. LCWA and WBWA are owned by the state of Delaware and are managed by Delaware Natural Resources and Environmental Control (DNREC). We examined only soybean fields at LCWA and corn at WBWA, as the two fields with

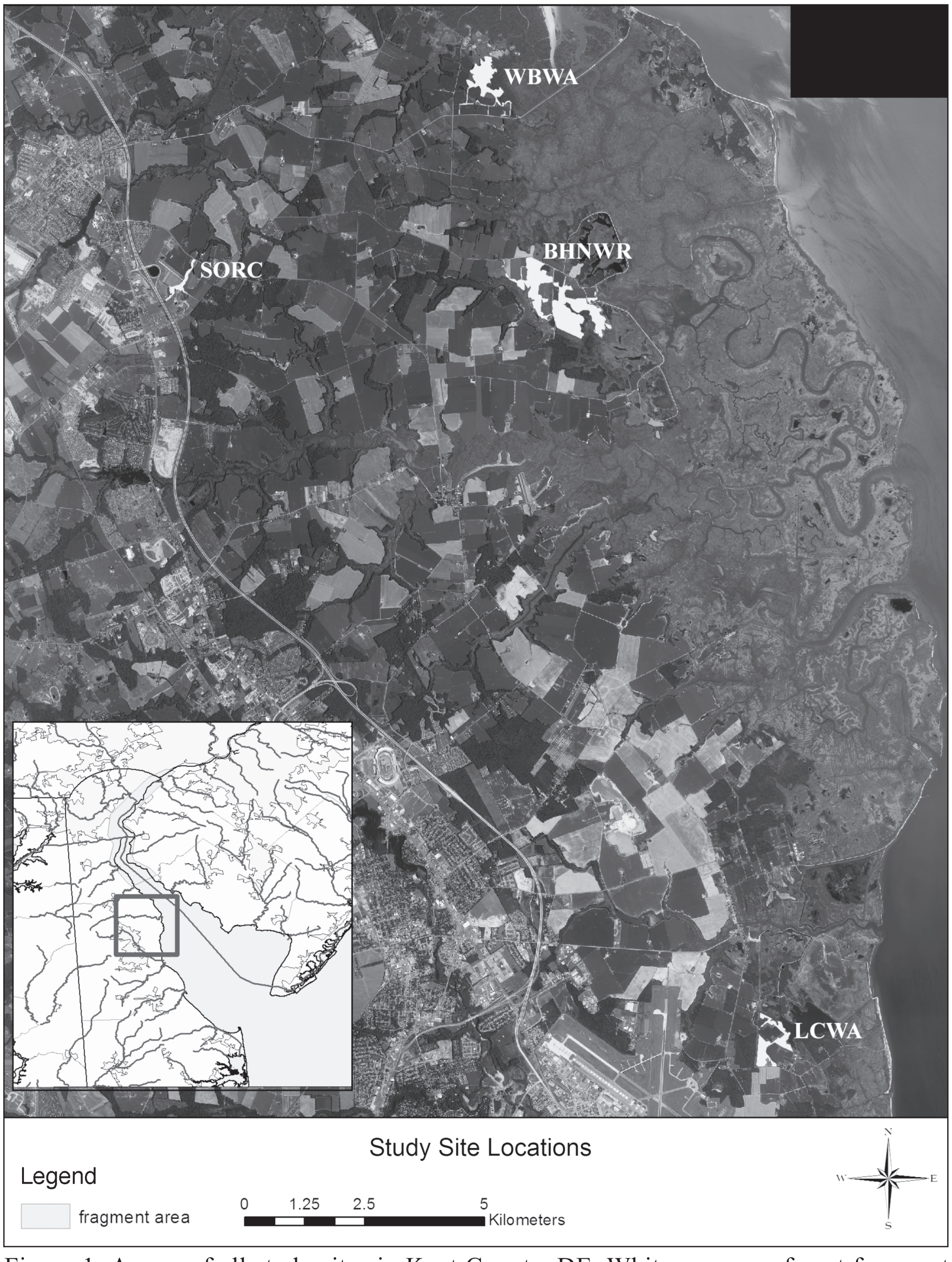

Figure 1. A map of all study sites in Kent County, DE. White areas are forest fragment polygons at each site: Little Creek Wildlife Area (LCWA), Bombay Hook National Wildlife Refuge (BHNWR), Smyrna Agricultural Outreach and Research Center (SORC), and Woodland Beach Wildlife Area (WBWA).

these crops were the only ones that had at least one side bordered by a forest fragment. We considered BHNWR, SORC, LCWA, and WBWA to be separate sites. Fields containing hay, winter wheat, and clover were pooled as small grain/forage fields because their height and density were similar; corn and soybean were the other crop types. Fields of the same crop type located within 200 m to each other were not considered to be independent and were therefore pooled and considered as one plot.

Methods

Effects of habitat, crop type, site, and weather variables on bat activity

We recorded bat activity using a Pettersson Ultrasound Detector D 240x™ (Pettersson Electronik, AB, Uppsala, Sweden). Because the detector does not have recording capabilities beyond the previous 1.7 seconds, data were stored in one of two ways. First, the detector was connected to a 512 megabyte (MB) iriver T30 MP3 player (Reigncom, Ltd.), which saved the passes until they could be later downloaded onto a laptop computer for analysis. The second method was to connect the detector directly to the laptop via a patch cable to record the files to the laptop. We set the Pettersson unit to record on time expansion (TE) with an automatic trigger of 1.7 seconds, the trigger level set to high frequency (HF), and the trigger source set to high. We set the expansion factor for the TE recordings at 10. The HF setting allows the Pettersson to be triggered by any high frequency signal, and the high setting allows for better recording in areas of high insect noise. Bat passes were quantified according to Fenton (1970), who "defined each sequence of one or more echolocation pulses with <1 s between sequential pulses as a pass by a bat." All passes were then downloaded into SonoBat™ 2.5.8 (SonoBat, Arcata, CA) for analysis.

We used a modified point-count protocol for sampling bat activity level. We sampled random observation points along the perimeter of the fields where the field edge meets the wooded edge and three random points from the middle of the fields to sample activity in open habitat. Sites were pre-selected each night by a random draw from a gridded map. Each habitat type was sampled three times each night. Since we were using active recording to examine bat activity at its peak—the first few hours after sunset—only one field in one site could be sampled per night. If the selected site contained more than one field (e.g., BHNWR), then the fields were given numbers, and a second random draw was performed to determine which field within the site was to be sampled. We defined open habitat as an open area in fields (of 2 ha or more) that was at least 30 m from the wooded edge. Since we had recorded the maximum detection distance for the Pettersson D240x in TE mode in an open habitat at 31.92 m (Wolcott 2008), point counts in areas >30 m from the forest edge would detect activity only in the open field habitat. We sampled passes from edges and center of the fields for alternating periods of ten minutes each (Verboom and Huitema 1997). Crop types were matched with fields of the same crop type at other sites as independent replicates.

Bat activity was measured as the number of passes/night and included commuting, searching, and feeding calls (Kuenzi and Morrison 2003, Murray and Kurta 2004). We measured relative activity because only the number of passes and not the absolute number of bats can be measured using acoustic detectors

(Kunz et al. 2007). We used passes/night as opposed to passes/minute to satisfy the assumption of independence among the replicates and to account for the issue of some loss of data during the time the data were recording to files from the Pettersson's D240x (Kunz et al. 2007). We recorded passes/night for the same total time period between open and edge habitats each night. We collected data over a period of 21 days between June and October 2007, and all data were collected in the first two hours after sunset, as this time period is the peak of bat activity in the area near our study sites (Fox 2007). Collection dates were heavily dependent on weather conditions.

We monitored weather variables during each sampling period using a Kestrel 3000 (Nielsen-Kellerman, Boothwyn, PA) handheld weather monitor. The weather variables recorded included: temperature (°C), average wind speed (kph), and relative humidity. For barometric pressure we used measurements from local forecasts at the Dover Air Force Base provided by the National Ocean and Atmospheric Association's National Weather Service website (www.nws.noaa.gov). We used passes/minute for this analysis so that differences among the 10-minute recording intervals could be examined.

Area and edge effects on bat activity

We took global positioning system (GPS) location points from all sites in February 2008 to generate maps of the study sites and determine the area, perimeter, and edge-to-interior ratios of the forested fragments adjacent to the agricultural fields. We overlaid all points onto aerial photos of Kent County taken in 2006. These images were accurate to within a meter. All maps were produced using ArcGIS 9.2 and digitized to a resolution of 1:7090. We calculated the interior-to-edge ratio by dividing the area of each fragment by its perimeter (Riley et al. 1998). We pooled the fields that shared fragments at each site and used a regression analysis to determine the effect of the fragment area and interior-to-edge ratio on bat activity (both commuting and foraging passes). One field at Bombay Hook was excluded from analysis because it was shared by two separate fragments. We constructed six polygons in ArcGIS 9.2 depicting the continuous fragments at all four study sites. Most fields were bordered by the same fragments or were divided by a hedgerow in the fragment. Hedgerows were included as part of the fragment in the polygons. One polygon each was made for SORC, LCWA, and WBWA. Three polygons were produced for the fields at BHNWR. We calculated the perimeter, area, and edge-to-interior ratio for each polygon in all sites (Table 1).

Statistical analyses

Due to the non-normality of passes/night count data, we used a generalized linear model (GLM) procedure with a negative binomial distribution using a log link function for acoustic analyses (Morris et al. 2010). Negative binomial fit the data better than Poisson (AIC = 392 vs. 878, respectively). Significances were calculated with Wald's chi-square statistic. We compared bat activity (passes/night) to site, habitat type, and crop type, and examined interactions between site x habitat and crop x habitat. There were not enough replicates of each crop type per site to compare crop x site or the three-way interaction. In addition, we compared bat activity to weather variables (temperature, wind speed, relative humidity, and barometric pressure) using a Kendall rank correlation. We examined fragment size and interior-to-edge ratio of each site and localized bat activity using the GLM procedure described above. We used SPSS Statistics Version 17.0 for Windows (SPSS, Inc., Chicago, IL) for all statistical tests.

Results

Effects of site, habitat type, crop type, and weather variables on bat activity

We sampled 11 fields (3 corn, 5 soybean, and 3 small grain/forage). We collected a total of 1672 passes over 21 days during the main activity season (early June to late September). We sampled each site the following number of nights: BHNWR = 16, LCWA = 10, SORC = 6, and WBWA = 8. We sampled habitat and crop types for the following number of collecting-nights: edge habitat = 21 and open habitat = 21, and corn crop= 12, grain crop= 12, and soybean crop = 18.

Bat activity was not significantly different among sites ($\chi^2 = 5.14$, df = 3, $P = 0.16$; Fig. 2), but was significantly different between the center of the fields and edges ($\chi^2 = 16.44$ df = 1, $P \leq 0.001$; Fig. 3). Bat activity was not significantly different among crop types, although grain/forage has a lower average bat activity than the other two crop types ($\chi^2 = 3.16$, df = 2, $P = 0.21$; Fig. 4). The interactions between site x habitat or between crop x habitat were not significant ($\chi^2 = 0.84$, df = 2, $P = 0.84$; $\chi^2 = 2.19$, df = 3, $P = 0.33$; respectively).

Passes/minute were negatively correlated with temperature ($\tau = -0.142$, $P = 0.023$) and wind speed ($\tau = -0.139$, $P = 0.047$), but were positively correlated with relative humidity ($\tau = 0.213$, $P = 0.001$) and barometric pressure ($\tau = 0.196$, $P = 0.002$).

Area and edge effects on bat activity

Fragment area did not significantly affect passes/minute (F=1.47, df =5, P= 0.29). There was also no significant difference between interior-to-edge ratio and passes/minute (F =2.25, df = 5, P = 0.21).

Table 1. Perimeter, area, and interior-to-edge ratio for the polygons from the 4 sites sampled with Pettersson bat detectors during the field season.

Site[1]	Fields[2]	Perimeter (km)	Area (km^2)	Area-to-perimeter ratio
LCWA		6.03	0.27	0.04
BHNWR	Parson's Point	1.32	0.02	0.02
BHNWR	Finnis Pool/Parson's Point	7.74	0.64	0.08
BHNWR	Allee House	7.32	0.42	0.06
SORC		4.77	0.10	0.02
WBWA		9.42	0.36	0.04

[1]Bombay Hook National Wildlife Refuge (BHNWR), Little Creek Wildlife Area (LCWA), Smyrna Agricultural Outreach and Research Center (SORC), and Woodland Beach Wildlife Area (WBWA).

[2]Refers to description of the geographic location of each field in the site and does not relate to crop type. This is only relevant to BHNWR, which is the only site with multiple fragments.

Discussion

Effects of habitat, crop type, site, and weather variables on bat activity

Our results show that bats were more active near the interface of the agricultural fields and the forest (i.e., edge habitats; Fig. 3) than open fields, a result generally consistent with previous research on bat activity (Furlonger et al. 1987, Hayes and Loeb 2007, Morris et al. 2010, Rogers et al. 2006). There are several hypotheses to explain this behavior, including protection from wind during the bats' foraging near vertical strata or the use of edges for navigation guides (Verboom and Huitema 1997, Verboom and Spoelstra 1999). Other studies indicate that insect abundance is also higher in edge habitat, which may increase foraging opportunities (Verboom and Spoelstra 1999). In our study, crop type was not found to be a significant factor influencing bat activity, but edges were. This result suggests that the edges themselves are important to bats.

The level of bat activity at each site may be influenced by land management practices (e.g., use of pesticides; Wickramasinghe et al. 2004). An estimated 445 hectares at BHNWR are designated for agriculture. The agricultural practices at the refuge include fertilizing, green manure cropping, and liming (O. Reed, US Fish and Wildlife Service, Bombay Hook National Wildlife Refuge, Smyrna, DE, pers. comm.). SORC treats the commercial fields (corn and soybeans) with herbicides

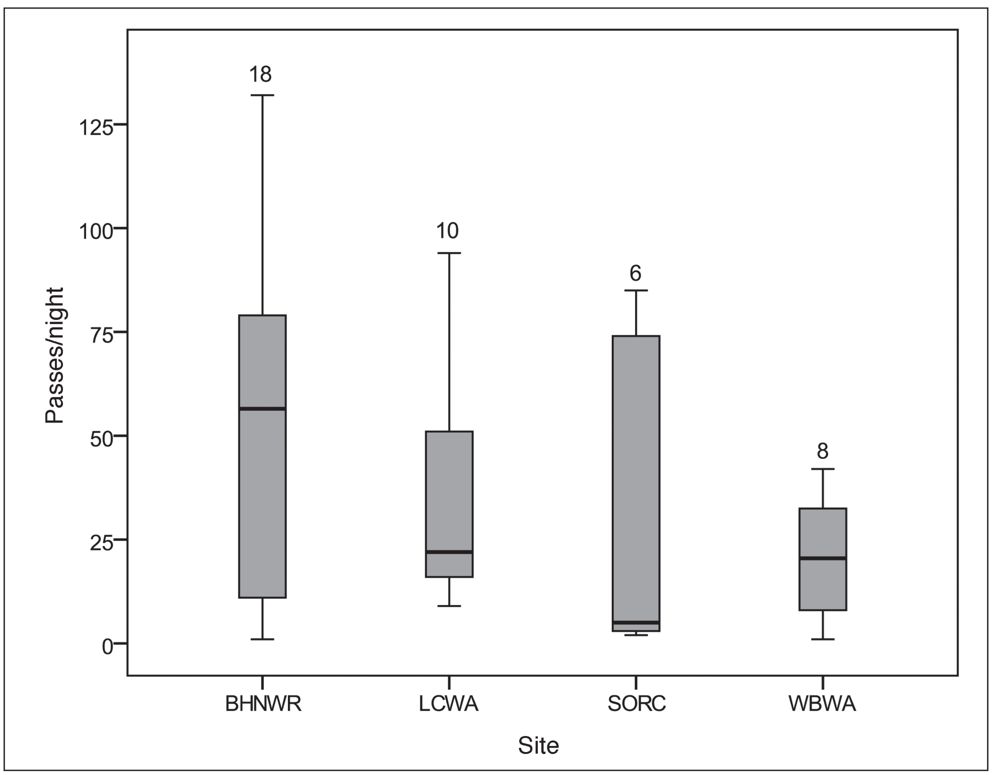

Figure 2. Comparison of average bat activity (passes per night) at each study site. The central line in the shaded box represents the median, the box encompasses the 25th and 75th quartiles, and the whiskers include the range of data. Sample size is included above each box. (χ^2 = 5.14, df = 3, P = 0.16).

to prevent weed growth but does not treat the fields with insecticides or fungicides (R. Peiffer, Delaware State University, Dover, DE, pers. comm.). These practices are compatible with biological pest management, and may allow more insect abundance that encourages bat foraging. However, managers at this site plant Bt corn, a pest-resistant strain, which may negatively affect insect abundance.

DNREC leases out the agricultural fields in the State Wildlife Areas to local farmers who manage the fields within certain guidelines issued by the agency. The state sprays the edges with herbicides to control woody brush. LCWA also contains mosquito impoundments that are managed by the state. These impoundments are treated with pesticides to control the mosquito population (W. Lehman, Delaware Division of Fish and Wildlife, Viola, DE, pers. comm.) and thus, may also contain chemicals that alter prey availability.

Our study showed that bat activity might be influenced by barometric pressure, which is consistent with other results in the same area (Fox 2007). For example, *Perimyotis subflavus* Cuvier (Tri-colored Bat) uses cues from changes in barometric pressure to evaluate foraging opportunities (Paige 1995). We found an increase in activity with increasing barometric pressure. Past studies have also found that ambient temperature affects bat activity (Vaughan et al. 1997). In our

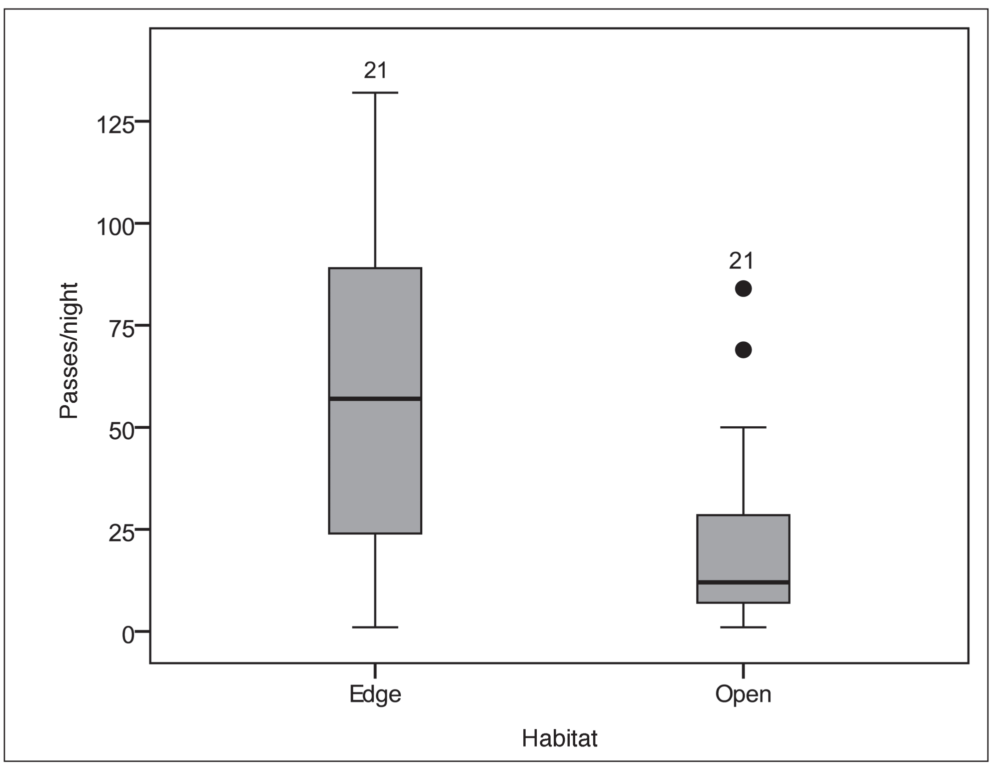

Figure 3. A comparison of bat activity (passes per night) in each habitat type (edge versus open). The central line in the shaded box represents the median, the box encompasses the 25th and 75th quartiles, and the whiskers include the range of data. Values more than 1.5 interquartile ranges (IQR's) but less than 3 IQR's from the end of the box are labeled as outliers (•). Sample size is included above each box. (χ^2 = 16.44, df = 1, $P \leq 0.001$).

study, bat activity declined with temperatures between 15 and 30 °C; however, Fox (2007) found a positive relationship between activity and temperature at BHNWR. Another study determined that activity increased with increasing temperature to a maximum between 17 and 21 °C, but declined with temperatures over 21 °C (Brooks 2009). Weather effects are also highly species specific (Burles et al. 2009); however, we did not examine individual species in this study.

Adjoining forest fragment size did not have a significant impact on bat activity at any of the sites. Nevertheless, BHNWR had the largest amount of continuous forested tracts compared to the other sites (Table 1) and had higher levels of bat activity than the other sites. The refuge has 445 hectares of impounded freshwater pools and swamps (USFWS 2004), providing ample water sources for wildlife populations, including bats. SORC has a small stream within the forest fragment that may be utilized as a water source, and the farm also has a substantial pond that may also be large enough for bats to drink from while on foraging bouts. LCWA and WBWA are adjacent or in close proximity to Delaware Bay; however, the Bay is not a suitable water source for bats due to high salinity (Gay and O'Donnell 2008).

This study provides data which suggests that edge habitat is important to sustain high levels of bat activity in Kent County, DE. Land-use practices should

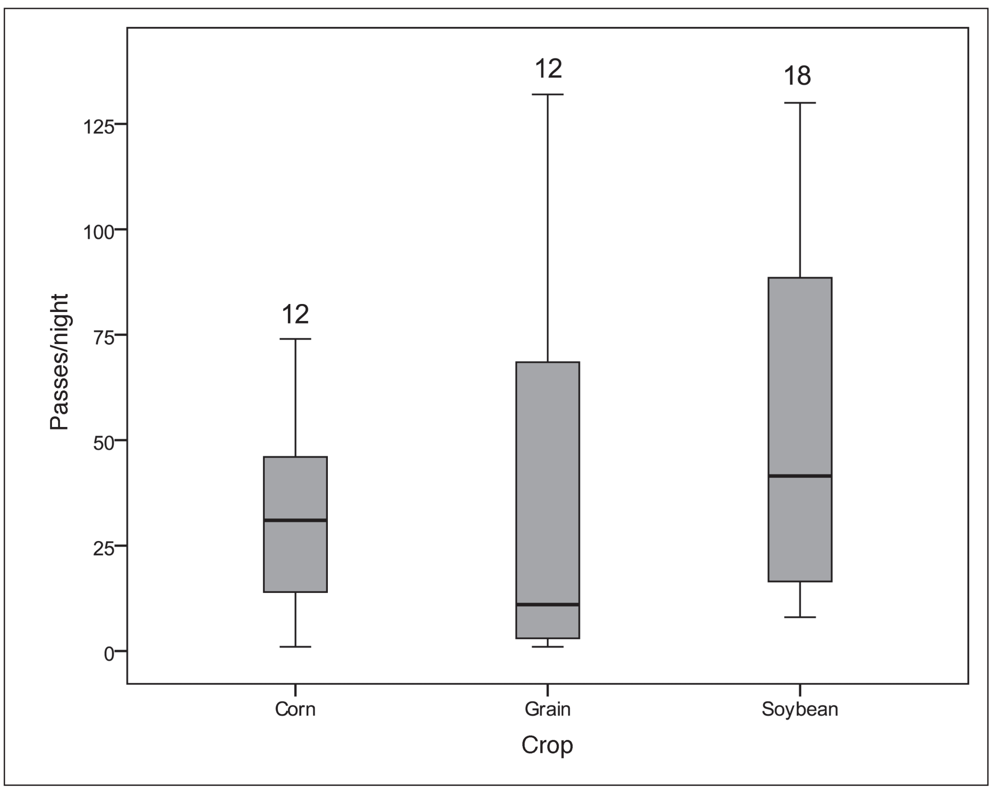

Figure 4. Comparison of average bat activity (passes per night) in different crop types. The central line in the shaded box represents the median, the box encompasses the 25th and 75th quartiles, and the whiskers include the range of data. Sample size is included above each box. (χ^2 = 3.16, df = 2, P = 0.21).

endeavor to conserve forested habitats within the state; nevertheless, this forest is likely to remain as thin strips of edge habitat for the near future. Thus, the availability of forest interior for bats in Delaware is expected to be low, making the conservation of thin strips of edge habitat even more important. Local wildlife refuges are managed for wildlife species such as deer, waterfowl, and migratory birds (DNREC 2006, USFWS 2004), so it is possible that management programs for bats may be developed and implemented as well. The total amount of edge or area was not significant in our study, thus we suggest that even small edges along crop fields provide habitat for foraging bats. With increasing development on the Delmarva Peninsula, bats must contend with decreasing habitat availability. We recommend that farms retain or replant forest edges around fields and maintain tree lines. Management strategies should also emphasize the need to conserve corridors and riparian strips to serve as flyways. Pesticide use and the planting of pest-resistant crop strains like Bt corn decrease prey availability in these areas; these factors could affect bat populations not only in terms of fewer food resources, but also have the potential of harming bats through the accumulation of pesticides in the body (Clawson and Clark 1989, Wickramasinghe et al. 2004). Further research in this area is required to determine if the use of pest-resistant crops and pesticides affect prey availability for bats.

Acknowledgments

Funding for this project was provided by the United States Department of Agriculture (USDA) Natural Resource Conservation Services; the USDA Cooperative State Research, Education, and Extension Service; the First State Resource Conservation and Development Council, Inc; and Delaware State University. We are also grateful to Richard Barczewski, Robert Naczi, Dana Limpert, and 2 anonymous reviewers for their comments on the study. Special thanks are also owed to Darren A. Miller for his valuable comments on an earlier version of the manuscript. Lori Brown assisted with the development of the GIS maps of our agricultural sites. Gary Page also provided technical assistance and comments on the manuscript and for that we are grateful. Thanks to Liang Liu for clarification of some statistical issues. Many thanks are also due to Ashleigh Green, Ayasha Jones, David Mellow, Johnna Fay, Jonathan McKenzie, and Kevin Neves for their help in the field. We would also like to thank Wayne Lehman at DNREC and the staff at Bombay Hook National Wildlife Refuge for their expertise and assistance with permits, support, and background information on our study sites. The opinions and views expressed in this article do not necessarily represent the views of the United States, the Federal Energy Regulatory Commission (FERC), individual FERC Commissioners, or FERC staff.

Literature Cited

Allen, T.H. 2009. The transformation of forest and marsh in the agricultural landscape of the Lower Delmarva Peninsula. Geocarto International 24:37–46.

Brooks, R.T. 2009. Habitat-associated and temporal patterns of bat activity in a diverse forest landscape of southern New England, USA. Biodiversity and Conservation 18:529–545.

Burles, D.W., R.M. Brigham, R.A. Ring, and T.E. Reimchen. 2009. Influence of weather on two insectivorous bats in a temperate Pacific Northwest rainforest. Canadian Journal of Zoology 87:132–138.

Clawson, R.L., and D.R. Clark, Jr. 1989. Pesticide contamination of endangered Gray Bats and their food base in Boone County, Missouri, 1982. Bulletin of Environmental Contamination and Toxicology 42:431–437.

Davy, C.M., D. Russo, and M.B. Fenton. 2007. Use of native woodlands and traditional olive groves by foraging bats on a Mediterranean island: consequences for Conservation. Journal of Zoology 273:397–405.

Department of Natural Resources and Environmental Control (DNREC). 2006. Delaware Wildlife Action Plan 2007–2017. Division of Fish and Wildlife, Natural Heritage and Endangered Species Program. Dover, DE.

Downs, N.C., and P.A. Racey. 2006. The use by bats of habitat features in mixed farmland in Scotland. Acta Chiropterologica 8:169–185.

Federico, P., T.G. Hallam, G.F. McCracken, S.T. Purucker, W.E. Grant, A.N. Correa-Sandoval, J.K. Westbrook, R.A. Medellín, C.J. Cleveland, C.G. Sansone, J.D. López, Jr., M. Betke, A. Moreno-Valdez, and T.H. Kunz. 2008. Brazilian Free-tailed Bats as insect pest regulators in transgenic and conventional cotton crops. Ecological Applications 18:826–837.

Fenton, M.B. 1970. A technique for monitoring bat activity with results obtained from different environments in southern Ontario. Canadian Journal of Zoology. 48:847–851.

Fischer, J., A. Zerger, P. Gibbons, J. Stott, and B. S. Law. 2010. Tree decline and the future of Australian farmland biodiversity. Available online at http://www.pnas.org/content/107/45/19597.full. Accessed 31 October 2010.

Fox, M. 2007. Bat species occurrence and habitat use at Bombay Hook National Wildlife Refuge. M.Sc. Thesis. Delaware State University, Dover, DE.

Furlonger, C.F., H.J. Dewar, and M.B. Fenton. 1987. Habitat use by foraging insectivorous bats. Canadian Journal of Zoology 65:284–288.

Gay, P., and J. O'Donnell. 2008. Comparison of the salinity structure of the Chesapeake Bay, the Delaware Bay, and Long Island Sound using a linearly tapered advection-dispersion model. Estuaries and Coasts 32:1559–2723.

Geggie, J.F., and M.B. Fenton. 1985. A comparison of foraging by *Eptesicus fuscus* (Chiroptera: Vespertillionidae) in urban and rural environments. Canadian Journal of Zoology 63:263–266.

Gibson, R.H., S. Pearce, R.J. Morris, W.O.C. Symondson, and J. Memmott. 2007. Plant diversity and land use under organic and conventional agriculture: A whole-farm approach. Journal of Applied Ecology 44:792–803,

Hayes, J.P., and S.C. Loeb. 2007. The influences of forest management on bats in North America. *In* Michael J. Lacki, John Parker Hayes, and Allen Kurta (Eds.). Bats in Forests: Conservation and Management. Johns Hopkins University Press, Baltimore, MD.

Hein, C.D., S.B. Castleberry, and K.V. Miller. 2009. Site-occupancy of bats in relation to forested corridors. Forest Ecology and Management 257:1200–1207.

Jones, G., D.S. Jacobs, T.H. Kunz, M.R. Willig, and P.A. Racey. 2009. Carpe noctem: The importance of bats as bioindicators. Endangered Species Research 8:93–115.

Kee, E. 2007. Delaware Farming. Arcadia Publishing, Charleston, SC. 129 pp.

Kuenzi, A.J., and M.L. Morrison. 2003. Temporal patterns of bat activity in southern Arizona. Journal of Wildlife Management 67:52–64.

Kunz, T.H., E.B. Arnett, B.M. Cooper, W.P. Erickson, R.P. Larkin, T. Mabee, M.L.. Morrison, M.D. Strickland, and J.M. Szewczak. 2007. Assessing impacts of wind-energy development on nocturnally active birds and bats: A guidance document. Journal of Wildlife Management 71:2449–2486.

Lacki, M.J., J.P. Hayes, and A. Kurta. 2007. Bats in Forests: Conservation and Management. Johns Hopkins University Press, Baltimore, MD.

Law, B.S., and M. Chidel. 2006. Eucalypt plantings on farms: Use by insectivorous bats in southeastern Australia. Biological Conservation 133:236–249.

Lewis, T., and G.C. Dibley. 1970. Air movement near windbreaks and a hypothesis of the mechanism of the accumulation of airborne insects. Annals of Applied Ecology 38:557–570.

Liu, X., and L. Lynch. 2011. Do agricultural land preservation programs reduce farmland loss? Evidence from a propensity score matching estimator. Land Economics 87:183–201.

Mix, T., and R. Hurley. 2008. Fiscal impacts of development: Literature review and discussion. Institute of Public Administration Planning Services Report. University of Delaware, Newark, DE.

Morris, A.D., D.A. Miller, and M.C. Kalcounis-Rueppell. 2010. Use of forest edges by bats in a managed pine forest landscape. Journal of Wildlife Management 74:26–34.

Murray, S.W., and A. Kurta. 2004. Nocturnal activity of the endangered Indiana Bat (*Myotis sodalis*). Journal of Zoology, London 262:197–206.

Paige, K.N. 1995. Bats and barometric pressure: Conserving limited energy and tracking insects from the roost. Functional Ecology 9:463–467.

Riley, S.P.D., J. Hadidian, and D.A. Manski. 1998. Population density, survival, and rabies in Raccoons in an urban national park. Canadian Journal of Zoology 76:1153–1164.

Rogers, D.S., M.C. Belk, M.W. González, B.L. Coleman, and C.W. Edwards. 2006. Patterns of habitat use by bats along a riparian corridor in northern Utah. The Southwestern Naturalist 51:52–58.

Sparks, D.W., C.M. Ritzi, J.E. Duchamp, and J.O. Whitaker, Jr. 2005. Foraging habitat of the Indiana Bat (*Myotis sodalis*) at an urban-rural interface. Journal of Mammalogy 86:713–718.

Tipping, P.W., C.A. Holko, and R.A. Bean. 2005. *Helicoverpa zea* (Lepidoptera: Noctuidae) dynamics and parasitism in Maryland soybeans. The Florida Entomologist 88:55–60.

US Fish and Wildlife Service (USFWS). 2004. Bombay Hook National Wildlife Refuge. Washington, DC.

Vaughan, N., G. Jones, and S. Harris. 1997. Habitat use by bats (Chiroptera) assessed by means of a broad-band acoustic method. Journal of Applied Ecology 34:716–730.

Verboom, B., and H. Huitema. 1997. The importance of linear landscape elements for the Pipistrelle, *Pipistrellus pipistrellus,* and the Serotine Bat, *Eptesicus serotinus*. Landscape Ecology 12:117–125.

Verboom, B., and K. Spoelstra. 1999. Effects of food abundance and wind on the use of tree lines by an insectivorous bat, *Pipistrellus pipistrellus*. Canadian Journal of Zoology 77:139–1401.

Weber, T., A. Sloan, and J. Wolf. 2006. Maryland's green infrastructure assessment: Development of a comprehensive approach to land conservation. Landscape and Urban Planning 77:94–110.

Wickramasinghe, L.P., S. Harris, G. Jones, and N, Vaughan. 2003. Bat activity and species richness on organic and conventional farms: Impact of agricultural intensification. Journal of Applied Ecology 40:984–993.

Wickramasinghe, L.P., S. Harris, G. Jones, and N. Vaughan. 2004. Abundance and species richness of nocturnal insects on organic and conventional farms: Effects of agricultural intensification on bat foraging. Conservation Biology 18:1283–1292.

Wolcott, K.A. 2008. Foraging activity of insectivorous bats at the woodland/farmland interface in agricultural fields. M.Sc. Thesis. Delaware State University, Dover, DE.