BAT ACTIVITY ON GOLF COURSES IN DELAWARE

By

Megan Ann Wallrichs

A THESIS

Submitted to the Faculty of Delaware State University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Natural Resources in the Department of Agriculture and Natural Resources.

Dover, Delaware
May 2019

This thesis is approved by the following members of the Final Oral Review Committee:

Dr. Kevina Vulinec, Committee Chair Person, Department of Agriculture and Natural Resources, Delaware State University

Dr. Richard Barczewski, Committee Member, Department of Agriculture and Natural Resources, Delaware State University

Dr. Christopher M. Heckscher, Committee Member, Department of Agriculture and Natural Resources, Delaware State University

Dr. Elizabeth Braun, External Committee Member, Fish and Wildlife Research Institute, Florida Fish and Wildlife Conservation Commission

DEDICATION

To my sister, Lauren, because I said that I would.

ACKNOWLEDGMENTS

I am grateful for all the help, support, encouragement that has made it possible for me to complete my master's degree. I am very appreciative of my advisor, Dr. Vulinec, and my other Delaware State University faculty committee members, Dr. Heckscher and Dr. Barczewski, for their enduring guidance and support throughout this process. I would like to express my deepest gratitude to Dr. Braun, my external committee member, for her mentorship and persistent encouragement.

This project would not have been possible without the golf course managers at Caroline County Country Club (Denton, MD), Deerfield Golf and Tennis Club (Newark, DE), Frog Hollow Golf Club (Middletown, DE), Garrisons Lake Golf Club (Smyrna, DE) and Sussex Pines Country Club (Georgetown, DE, now known as Mulligan's Pointe). Thank you for allowing me to study the bats on your golf courses. Financial support for this project was provided by the National Fish and Wildlife Foundation (Grant ##2009-0041-004) and Delaware State University.

I would also like to express my gratitude to all those who assisted me in the field and lab: Andrea Stoneman, Kesha Braunskill, Ileana Garcia-Mayes, John Hayes, Brandon Bruce, Ashton Haynes, Kate Foster, Paytawn Erskine, and Dave Mellow.

The encouragement, prodding, and inspiration from my colleagues and mentors at the Florida Fish and Wildlife Conservation Commission has been much appreciated. Thank you, especially to Blair Hayman and Terry Doonan, for your professional guidance over the years.

Lastly, I am indebted to my parents, my sister, my partner, Jake, and my many dear friends, whose unwavering support has been an immeasurable gift.

BAT ACTIVITY ON GOLF COURSES ON THE DELMARVA PENINSULA

Megan Ann Wallrichs

Faculty Advisor: Kevina Vulinec, Ph.D.

ABSTRACT

Due to landscape modifications and chemical use, golf courses have earned a negative reputation among some environmental groups, but their park-like landscapes may offer habitat for some wildlife species, especially over other land use types. In this study, I monitored bat activity using ultrasonic acoustic detectors in different small-scale habitats found on golf courses on the Delmarva Peninsula. My objective was to evaluate if and how bats are using course landscapes. I found differences in overall activity levels at the habitat level but not on different golf courses. Areas with closed canopy and open understory that were managed had significantly higher activity than other four habitats that reflected more natural habitats (open grass, dense canopy forest fragment, and open canopy forest fragment). The open understory managed areas also had significantly higher foraging activity than the other four habitats. Six of the eight bat species thought to occur on the Delmarva Peninsula were recorded, but *Eptesicus fuscus* and *Lasiurus borealis* dominated bat activity across all golf courses and habitats and had highest activity in open understory managed habitat. These findings indicate that bats are using golf courses on the Peninsula regularly as flyways and foraging grounds, and even substantially disturbed areas are used extensively. This study adds to the growing body of literature that positive partnerships can be created between wildlife and golf courses.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter I:

Introduction

Golf courses offer outdoor recreation opportunities in a park-like landscape. Despite the "natural" appearance of golf course premises, courses across the globe are under scrutiny because of the many real and perceived negative environmental effects associated with the construction and maintenance of a course. However, in light of increased urbanization and wildlife habitat loss, golf courses may offer one of the few development types that do provide wildlife habitat. A variety of wildlife species can be found inhabiting golf courses and studies have focused on investigating the potential for golf courses to serve as refuges across several taxa. Urban-adapted species tend to thrive on courses, while disturbance-sensitive species generally fare more poorly. Much of the literature has focused on the effects of golf courses on birds but other studies have concentrated on insects, amphibians, and some small mammals. There is a lack of information on the use of golf courses by bats (Order Chiroptera).

As an important insect predator, bats could potentially benefit from foraging and roosting at golf courses. Many landscape features on golf courses mimic natural features that bats are known exploit, yet little work has attempted to explore bats' use of these manicured landscapes.

Bat populations face many threats and determining bats' presence on golf courses and investigating how they use the local landscape in order to maximize a golf course's potential as a habitat refuge, could be an important step towards their conservation. Additionally, greenskeepers may benefit from the pest control services that bats provide. Therefore, the general objective of this study was to investigate if and how bats are using golf course landscapes and to use the results to make management recommendations for more bat-friendly golf courses.

Study Objectives

I. Examine the effects of five small-scale golf course landscape variables (water hazard, open grass, open understory managed, open understory natural, and dense understory natural habitats) on 1) general bat activity, 2) foraging activity, 3) species richness and 4) species-specific activity using acoustical survey methods.

Chapter II contains a thorough literature review on golf courses and wildlife, bat biology and life history, and the use of acoustic surveys for bat research. Chapter III details the methods used to accomplish the outlined objectives of this study. Chapter IV reports the results of the study followed by a discussion of the results in Chapter V.

Although this project is limited in geographic scope to golf courses in Delaware, this study is the first to investigate bats on golf courses and serves as a critical first step towards understanding bat habitat use on golf courses. Golf courses across the United States share many similar physical landscape features, and results from this study may be applicable to golf courses in a range of ecological systems.

Chapter II:

Literature Review

Golf Course History and Environmental Impact

It is generally thought that the game of golf began in Scotland with St. Andrews Golf Club being described as the "birthplace of golf." While the rules of the game have fundamentally stayed the same, today's golf courses are much different than St. Andrews and other historical courses. The design of the first courses to be established was determined by the existing landscape. Golfers took advantage of existing features (rolling hills, naturally short grass, or dirt pits created by sheep herds) to create a diverse and challenging course (Stuller 1997). The landscape was not specifically modified or manicured for playing purposes.

With the first major televised golf event in 1968, The Master's Tournament forever changed the way spectators, players, and golf course greenskeepers viewed golf course aesthetics. Termed the "Augusta National Syndrome," every golf course strove to mimic the intensely manicured grounds at Augusta National Golf Course, the home of the annual Master's Tournament (Wheeler and Nauright 2006). Consequently, efforts associated with turf maintenance and manicured landscapes have been detrimental to the environment.

Construction of a golf course is commonly associated with deforestation and major clearing of natural vegetation, often being replaced by non-native plants (Winter et al. 2003, Kuvan 2010). To provide a more challenging game, the golf course landscape is sometimes disturbed and molded through considerable changes of topography and hydrology of the land (Winter and Dillon 2005). Additionally, golf course construction is usually accompanied by increased urbanization: housing developments, shopping malls, roads, and sometimes airports (Kuvan 2005, Wheeler and Nauright 2006, Kuvan 2010). Urbanization is widely accepted as a leading and persistent cause of habitat loss (Czech 2000, Czech et al. 2000, Marzluff 2001, McIntyre 2001, McKinney 2002, Turner et al. 2004). Golf course construction and the subsequent associated development have the potential to negatively impact many existing native habitats.

After a golf course is constructed, necessary maintenance practices can have continued adverse effects on the environment and place a strain on natural resources. Chemical application has been a major primary concern of environmental scientists and citizens in the last few decades. Golf courses regularly apply insecticides, herbicides, fungicides (classified here as "pesticides"), and fertilizers to combat pests and promote turf grass growth. A 1982 study found in the Mid-Atlantic region of the United State, golf courses were applying 1000 -1500+ pounds (450-680+ kg) of pesticides per golf course per year (Cox 1991). In 1991, pesticide use per acre on golf courses was seven times that of agricultural pesticide use and without the benefit of food production (Attorney General Office of New York State 1991, Suzuki et al. 1998). In Southeast Asia, it is purported that courses use 1500kg per golf course per year (Chatterjee 1993). In the United States, Chamberlain (1995) estimated an average golf course will apply 22,680 kg of dry and liquid chemicals annually. Results from a comprehensive survey conducted by the Golf Course Superintendents Association of America reported a total of 101,096 tons of nitrogen and 36,810 tons of phosphate was applied to all U.S golf courses in 2006 (Golf Course

Environmental Profile Volume V 2012). For comparison, a total of 1.24 and 4.48 million tons of nitrogen and phosphate, respectively, were used for crop production in 2006 (corn, cotton, wheat, soybeans, and other) (USDA 2018). Pesticide runoff loads are a concern for the environment and society, but will vary depending on initial application load, local climate, and grass surface type (Haith and Duffany 2007).

Large-scale chemical applications of fertilizers and pesticides have been found to be damaging to wildlife populations on and around golf courses. Stansley et al. (2001) found chlordane (a popular underground turf treatment for termite control used until 1980s) responsible for recurring poisonings of birds and bats, as they were consuming insects that had high concentrations of chlordane in suburban areas with golf courses. Migratory waterfowl, such as American widgeon and Canada geese, often forage on turf grasses and several mortality events of these species have been associated with the application of such pesticides like diazinon (Kendall et al. 1993, Zinkl et al. 1978). The role of organophosphate pesticides in avian poisonings and deaths is well documented (Grue 1982, White et al. 1982, Henderson et al. 1994, Fry 1995, Rainwater et al.1995, Mitra et al. 2011). An incident at Sapporo Kokusai Country Club in Japan led to the death of over 90,000 fish after greenskeepers applied copper compounds to the turf to prevent it from dying underneath the snow (Chatterjee 1993). Additionally, there have been reports of non-fatal golf course pesticide poisonings in humans and elevated levels of brain, lymphoma, prostate, and large intestine cancers in golf course superintendents (Edmondson 1987, Cox 1991, Chatterjee 1993, Kross et al. 1996). Furthermore, golf courses require enormous amounts of water to keep the turf green and to fill water hazards (small to large ponds created as obstacles in the game). The large water consumption of golf courses sometimes equals or exceeds the water usage of the town itself (Platt 1994). In Southeast Asia, golf courses exceed water use needed by local families, and the local governments are bearing the costs associated with transporting the golf courses' water supply (Chatterjee 1993). The proposal for a golf course luxury resort to be built in a small Mexican town in the state of Morelos, estimated to need 800,000 gallons of water per day for construction (five times that of the normal daily use of its residents), led to riots and hostage situations (Hurriaga 1995). Golf courses in desert environments must pump water in from outside sources. Several golf courses in the Palm Springs, CA area draw in water from the already exhausted Colorado River Basin (Wheeler and Nauright 2006).

Mitigating negative interactions between the environment and golf courses should be a chief concern for both greenskeepers and environmental scientists as golf continues to increase in popularity across the globe. Despite a small drop in the number of golfers in the 2000s, the 2010s saw an overall increase in the number of golfers with over 23 million golfers in the United States, creating an $84.1 billion-dollar industry (SRI International for World Golf Foundation 2011, Ozawa et al 2016). Economic booms, rises of the middle class, social uses of golf to solidify business relationships, and the inclusion of golf in the 2016 Olympic Games contribute to expected trends of golfer increase worldwide (Futures Company for HSBC 2012). The United States currently has over 15,000 golf courses, and there are over 40,000 courses worldwide, with 400-600 new courses being built each year in Canada and The U.S. (Knopper and Lean 2004, 2012 HSBC Report). According to the 2018 U.S. Golf Economy Report, there was a net decline of 737 golf facilities from 2011 to 2016, but the construction of the surrounding golf communities increased 18.5%. Given the number of existing golf courses and the continued associated land development, and considering the park-like environment courses offer, it is critical to continue research investigating how environmental scientists and private industry can work together to ensure better outcomes for wildlife.

Golf Course Land Use and Wildlife Habitat Potential

Golf courses have the potential to play a key role in wildlife biodiversity conservation (Terman 1997, Tanner and Gange 2005, Colding and Folke 2009). Golf courses account for almost 930,00 hectares (2.3 million acres) of land in the U.S., comprising maintained turfgrass, natural areas, water bodies, facility buildings, bunkers, and parking lots (Golf Course Environmental Profile Phase II, Volume IV). According to the 2017 report released by the Golf Course Superintendent Association of America, the average size of 18-hole golf course in the United States in 2015 is 60ha (150 acres) of which 67% of the area is maintained turfgrass (Golf Course Environmental Profile Phase II, Volume IV; Figure 2.1).

Many manicured golf courses offer a heterogeneous landscape consisting of a variety of features. All courses generally feature 9-18 “holes” which consist of a tee, fairway, green, and the “rough.” While the tee, fairway, and green are well established and distinguished by the way they are maintained (short grass that is optimal for hitting a golf ball), the “rough” is anything outside these favorable playing areas and can be tall grass, a pond or stream, small forested areas, man-made sand traps or “bunkers”, or a combination of all these features. Different shapes, lengths, and lay of the fairways and greens with different features of the rough all contribute to the difficulty and enjoyment of the game and make each course unique. The heavily-manicured short grasses on the tees, fairways, and greens, sandy bunkers, buildings, and parking lots likely do not provide enough food, water, or shelter for wildlife and may not provide suitable habitat for most wildlife Those features make up approximately 40% of the total course landscape leaving 60% of the remaining landscape (forested fragment, man-made ponds, taller grassed areas or “roughs”) to be developed or managed in such a way to promote wildlife occupancy (Threlfall et al. 2017).

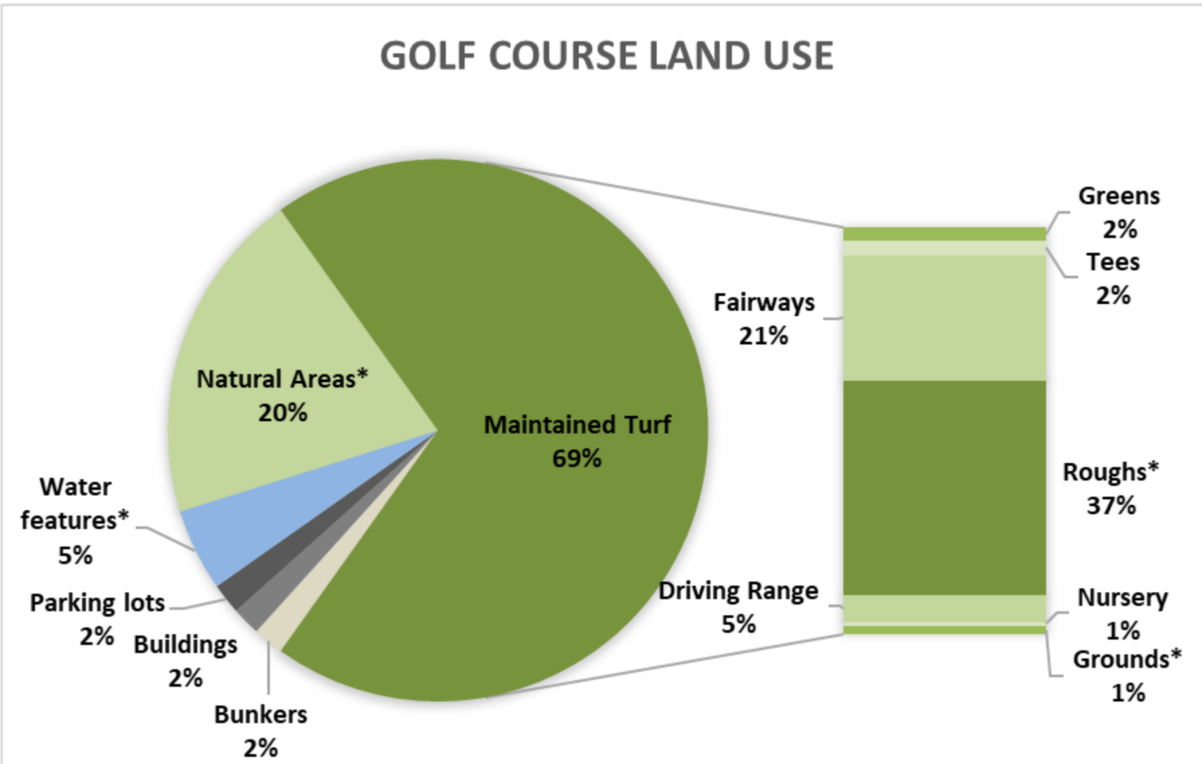


Figure 2.1 Percentage of land uses on a median-sized golf course in the United States in 2015. Asterisks indicate land use type that may provide potential wildlife habitat. Figure was created using data from the 2017 GCSAA Golf Course Environmental Profile Report

In light of the negative attention golf courses have received from environmental scientists in the last few decades regarding pesticide and water use, a multi-disciplinary meeting of golf course superintendents, environmental scientists, and concerned citizens was held in 1995

(Barton 2008). In the years after this meeting, more golf course managers and superintendents have since implemented more environmentally friendly and sustainable practices and researchers have begun to investigate golf courses' potential to serve as wildlife refuges. Alongside this push for more eco-friendly courses, several voluntary programs have been created through conservation organizations, like the Audubon Society, that offer programs and guidelines for golf courses that encourage increased wildlife inhabitance. Additionally, recognizing a lack of a comprehensive national dataset of management practices across the U.S. the Golf Course Superintendents Association of America (GCSAA) began to address this need in 2005 by conducting large scale surveys of golf course superintendents about their course management practices and have since published several reports summarizing their results. These reports have focused on characterizing and quantifying physical features, water, nutrient pesticide, and energy use at golf courses across the U.S. Data about environmental practices that golf course managers have implemented was also collected.

The GSCAA report found that 29% of 18-hole golf courses participate in some type of voluntary environmental stewardship program (GSCCA 2007). Whereas almost all courses have made an environmental improvement to the land, courses involved in the stewardship program have made significantly more improvements over a ten-year period (Golf Course Environmental Profile Phase I). Constructing or improving wildlife habitat, reducing waste, recycling, and improving chemical storage and irrigation systems are example of actions that golf courses have reported as environmental improvements (GCSSA 2012). However, an updated survey in 2015 found that participation in stewardship programs remained the same with a significant decrease in many types of environmental improvement (e.g. wetland restoration, erosion control, wildlife habitat, stormwater retention), with budget and time restrictions being the most frequent grounds for lack of participation (GSCCA 2017). Recycling was the only improvement that had an increase in participation from 2005 to 2015 (38% to 53%, respectively) (GSCCA 2017).

While golf course vegetation is not always an equal replacement for natural landscapes (especially if non-native plants are used), it may be more beneficial to wildlife than other types of urban development that completely eradicate natural features. Many baseline studies have shown that golf courses are able to support some wildlife species (Colding and Folke 2008). The Canada goose (*Branta canadensis*) has been so successful at occupying some golf courses in Delaware they have become a nuisance for greenskeepers and are strategically culled (J. Jacobs pers. comm.). Bird diversity was similar on Kansas golf courses to the surrounding natural areas but had lower relative abundance of most species (Terman 1997). Additional studies have analyzed life history and fitness metrics of species on golf courses. Eastern bluebirds on golf courses had lower reproductive rates at golf course sites than non-golf course sites in Virginia but were able to successfully reproduce at higher rates than that of other disturbed systems (Stanback and Seifert 2005, Cornell et al. 2011). Given the productivity of eastern bluebirds on some golf courses, courses may even be able to serve as a population source, allowing bluebirds to persist in the surrounding lower quality habitats (LeClerc et al 2005). Burrowing owls in Washington are attracted to the short turfgrass on golf courses and have successfully nested in artificial nest boxes placed away from maintained areas (Smith et al. 2005). Golf course ponds provide suitable habitat for many species of semi-aquatic turtles in the western piedmont of North Carolina (Failey et al. 2007). Different life history traits lead to variable rates of success of a species' ability to occupy a golf course habitat; thus, the potential of golf courses serving as a refuge should be evaluated on a species-specific basis (Hodgkison et al. 2007). Many bird, insect, amphibian, reptile, and small mammal species have been studied in the context of golf courses, but at the time of this study, little attention has been focused on bats (Chiroptera).

Bat (Chiroptera) Biology and Conservation Status

Bats are a diverse and ubiquitous group of volant mammals. With over 1200 species worldwide, they compose one-fifth of the known mammalian species, and within the United States there are 47 species with diverse life-histories (Harvey et al. 2011).

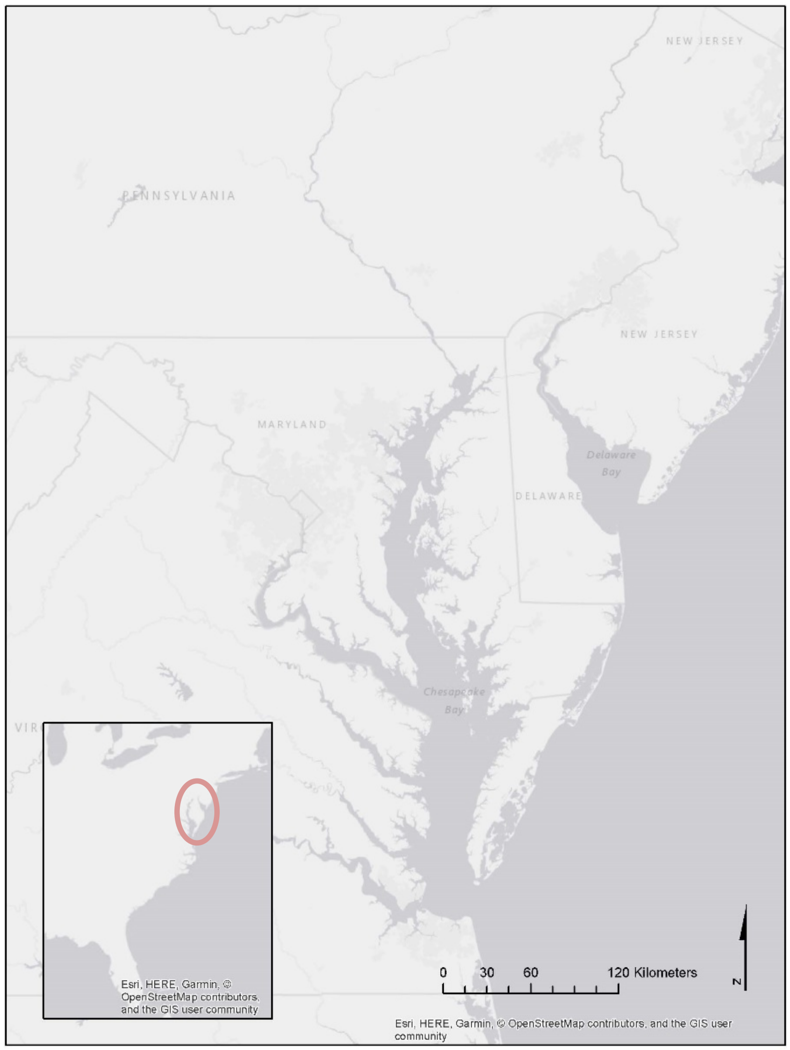


Figure 2.2 Location of Delaware on the mid-Atlantic coast, USA

In the Northeast and Mid-Atlantic region of the United States there are twelve species, and eight of these species are known within Delaware (Figure 2.2): *Lasiurus borealis* (Eastern red bat), *Lasiurus cinereus* (hoary bat), *Lasionycteris noctivagans* (silver haired bat), *Eptesicus fuscus* (big brown bat), *Myotis lucifugus* (little brown bat), *Myotis septentrionalis* (northern long-eared bat), *Perimyotis* *subflavis* (tri-colored bat, formerly known as *Pipistrellus subflavis*, the eastern pipestrelle), and *Nycticeius humeralis* (evening bat). These eight species can be divided into two groups: cave bats or tree bats. Cave bats are species that hibernate in caves over winter and form large maternity colony roosts away from their hibernacula in the summer, while adult male cave bats tend to roost alone or in small bachelor colonies. (Kunz 1982). They may also form maternity colonies in tree cavities, bat boxes, bridges, or other man-made structures. Tree bats are highly migratory and mostly solitary species that may hibernate under certain conditions (Cryan et al. 2003). These species typically are found roosting alone or in small family groups under loose bark or in clusters of leaves on a tree (Shump and Shump 1982, Barclay et al. 1988).

Delaware

Both cave bats and tree bats in the Northeast and Mid-Atlantic are insectivorous. Bats are the primary predator of night flying insects (Anthony and Kunz 1977, Cleveland et al. 2006). Coleoptera and Lepidoptera make up the majority of insectivorous bat diets (Black 1974). While bats eat a variety of insect species, bat morphology and foraging strategies have been shown to affect prey preference (Belwood and Fenton 1976; Fenton and Morris 1976, Feldhammer et al. 2009). Feldhammer et al. (2009) established a relationship between mean body mass of bats and prey hardness, where larger bats, such as *E. fuscus*, tended to eat mostly coleopterans. In southern Indiana, *L. borealis* were shown to prefer primarily lepidopterans, *N. humeralis* prefer coleopterans, *P. subflavus* prefer trichopterans, and *M. lucifugus* and *M. septentrionalis* prefer Lepidoptera and Coleoptera. Coleoptera, Lepidoptera, and Hemiptera are among the top preferred insects of *N. humeralis* (Whitaker Jr and Clem 1992). Regional and temporal differences will also affect prey preference flexibility and availability in insectivorous bats. While many studies show *E. fuscus* to be primarily a beetle-consumer, a colony on the

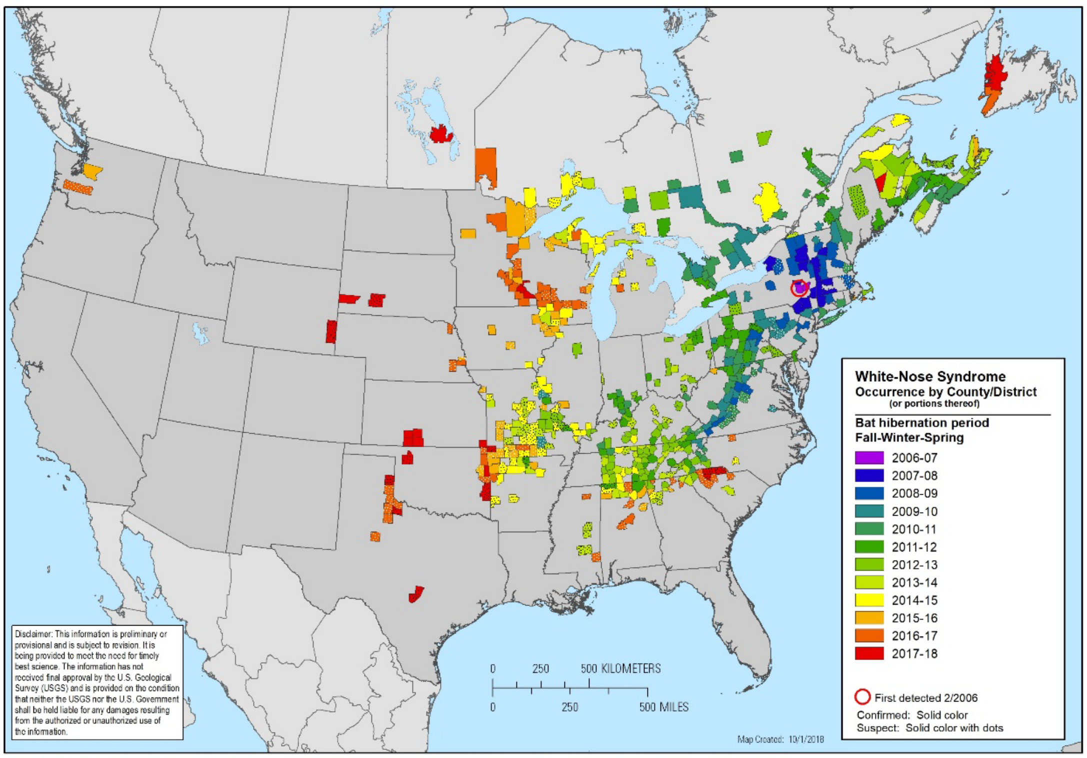
Pennsylvania/Delaware border was found to eat almost exclusively dipteran species (Black 1974, Balke et al. unpublished data).

As insectivores, bats are critical biological pest control agents (Kunz et al. 2011). Their pest control services are not only beneficial to human comfort and safety but have been estimated to be worth up to 57 billion US dollars to the agriculture industry annually (Boyles et al. 2011). Maine and Boyles (2015) conducted exclusion studies on corn fields and found that the presence of bats significantly reduced the number of pests and the presence of pest-associated fungi, resulting in an estimated 1 billion US dollars' worth of ecosystem services each year in corn production alone. A maternity colony of one million Brazilian free-tailed bats (*Tadarida brasiliensis*) can consume up to 8.4 metric tons of insects per night (Kunz et al. 1995). Kurta et al. (1989) estimated a 7.9g lactating female *M. lucifugus* can consume over 100% of her bodyweight in one night of foraging. Other native Delaware bat species such as *E. fuscus*, *L. noctivagans,* and *L. cinereus* can eat up to 25% of their weight in insects each night (Coutts et al 1973). In Delaware, it is estimated that bat pest control services are worth up to 17 million US dollars annually (Boyles et al. 2011). When referring to pest-control services of bats, it has often been reported that bats eat a large number of mosquitos (Order: Diptera), but there have not been many studies to support this statement. However, a recent study found that some species are eating more mosquitos than previously thought (Wray et al. 2018). Bats are also considered to be potential indicators of ecosystem integrity and important for maintaining forest health and potentially contribute to nutrient transport (Marcot 1996, Agosta 2002, Jones et al 2009).

In the last decade, bat conservation in the United States has become a top priority for many wildlife biologists. Bats in the United States face many novel problems that threaten their populations' existence. In 2006, an emerging fungal disease caused by *Psuedogymnoascus destructans* or *Pd* (formally known as *Geomyces destructans* or *Gd*), referred to as white-nose syndrome (WNS), was discovered (Blehart et al. 2009, Lorch et al. 2011). Since its discovery in Howe's Cave near Albany, New York in 2006, the disease has quickly spread throughout most of the Northeastern and Eastern United States; continuing with an unknown trajectory (Figure 2.3). At the end of the 2017-2018 hibernating season, WNS was present in 33 states in the US and 7 Canadian provinces affecting at least 11 species of bats (White-nose Syndrome Response Team 2018). White-nose syndrome seems to primarily affect cave bat species. Some tree bats have tested positive for *Pd* but have not been documented exhibiting any symptoms of white-nose syndrome. Cave bats' aggregating behavior while hibernating in cold, dark, and humid caves makes them an excellent target for *Pd*, a saprophytic psychrophilic fungus (Frick et al 2010, Turner et al. 2011). The spread of the disease is suspected to be primarily through bat-to-bat contact, and the extent of the role of humans or other animals in its spread is not fully understood (Turner et al. 2011). An isolated instance of a *Pd* positive little brown bat in

Washington state (1300 miles from the nearest detection in Nebraska) complicates our understanding of the pathogen spread (Lorch et al. 2016).

Since its discovery the United States Fish and Wildlife Service (USFWS) has estimated a loss of at least 5.5-6.7 million bats to WNS, with no guarantee of recovery in the next century



Citation: White-nose syndrome occurrence map - by year (2018). Data Last Updated: 10/1/2018. Available at: https://www.whitenosesyndrome.org/resources/map.

Figure 2.3 Spread map of white-nose syndrome across the United States and Canada since 2006. Map from www.whitenosesyndrome.org. Accessed 2/7/2019

and even potential regional extinction of the once common *M. lucifugus* (Frick et al 2010, USFWS 2012). White-nose syndrome seems to severely disrupt normal physiological processes in the hibernating bat, yet the exact cause of mortality is still unknown (Blehert et al. 2009, Cryan et al 2010). Symptoms of white-nose syndrome include increased arousals during winter hibernation, wing damage, visible white "fuzz" around the head and muzzle, dehydration, and depleted stores of body fat (Blehert et al. 2009, Cryan et al. 2010, Reeder et al. 2012, Cryan et al. 2013).

Wind turbines present another recent threat to bat populations. With the increased popularity of wind as an alternative energy source, there has been an unexpectedly high number of bat fatalities occurring at wind energy facilities across the US (Kunz et al. 2007a and Kunz et al. 2007b). It is estimated that wind turbines in the United States kill hundreds of thousands of bats annually (Hayes 2013). In contrast to white-nose syndrome, wind turbine fatalities largely affect the highly migratory tree bat species, as wind energy facilities are often placed along important fly-ways (e.g. ridge tops, coastal areas) that bats use during migration, but area-resident bats may also be affected (Cryan and Barclay 2009). Many hypotheses have been put forward as to why bats are much more affected by these turbines than birds, but a consensus among scientists has not yet been reached. Turbines may appear as a lekking structure, a potential roosting site, or may simply be a curiosity to passing bats (Horn et al. 2008, Cryan and Barclay 2009). Mortality has been shown to occur from blunt physical trauma from the blade and from pulmonary barotrauma (fatal tissue damage to lung structures due to rapid changes in air-pressure near the fast spinning turbine blades) (Baerwald 2008, Cryan and Barclay 2009, Grodsky et al. 2011). Some have suggested that barotrauma is not as prevalent as previous studies have suggested and traumatic injury from the turbine blades is likely the leading cause of bat mortality at wind farms (Capparella et al. 2012). Regardless of how bats are being killed by turbines, the high number of bats being killed by wind turbines is of great concern for conservationists.

Bats and Golf Courses

Habitat destruction and fragmentation is one of the top threats to most wildlife, including bats, and golf courses may offer a novel opportunity for the conservation of bats by providing suitable habitat (Tilman 1994). Golf courses offer many local landscape features that may be attractive to bats. Many species of bats have shown preference for hard tree line edge habitats that encourage successful foraging and commuting (Walsh and Harris 1996, Morris et al. 2010, Wolcott and Vulinec 2012). Tree lines edges are a ubiquitous feature on many golf courses that are manicured and designed to enhance game play difficulty. *Lasiurus. cinereus* show preference for foraging high over large open grass patches (Gruver 2002), features that are prominent on every golf course. Vindigni et al (2009) found that modified water sources in managed landscapes are important water and insect prey sources for bats. Higher levels of *E. fuscus* activity have been found near standing water (Krusic and Neefus 1996). Water hazards (man-made ponds created to add difficulty to the golf game) are another prevalent feature of golf courses that could provide a source of drinking water and foraging for bats. Additionally, many golf courses have partially unmaintained patches of forest, which may contain suitable day roosts for tree bats and/or cave bats forming maternity colonies. The availability of suitable day roosts is an important factor for bat habitat selection (Kunz 1982, Agosta 2002, Kalcounis-Rueppell et al. 2005, Limpert et al. 2007). Conserving and properly managing these areas that potentially contain day roosts may promote higher bat occupancy on golf courses. Recently, the endangered *Eumops floridanus,* Florida bonneted bat, was observed on a roosting in a tree on a golf course in Florida (Gore et al. 2015).

The combination of these features suggests a high potential for golf courses to provide roosting and foraging opportunities for bats and help mitigate the problem of habitat destruction.

Additionally, bats may provide valuable pest control services that could optimally result in the reduction of chemical use. Despite this potential, I could find no study that has quantified bat activity or habitat use on golf courses.

Acoustic surveys as a method to study bats

Bats' elusive nocturnal and aerial behaviors make them an inherently difficult organism to study. Additionally, the sounds bats make are most often outside of the audible range of humans (ultrasonic, approximately >20kHz). In the last two decades, technology for recording bat sounds has improved tremendously and has been increasingly used in studies to measure relative bat activity by recording bat echolocation sounds as they fly through the landscape (O'Farrell et al. 1999, Ochoa et al. 2000, Miller 2001, Flaquer et al 2007). These specialized acoustic monitoring devices (hereafter 'bat detectors') use microphones that detect and record high frequency sounds. The bat detectors I used in this project record sound in full-spectrum. Full-spectrum bat detectors record bat echolocation calls that are stored as hi-fidelity signals that retain all the original information of the signal, including information regarding power spectrum and temporal characteristics of the recording (Brigham et al. 2004). Compared to other types of recording, full-spectrum allows for improved recording in noisy environments.

Bat echolocation sounds are emitted as a series of short high-frequency pulses as the bat is flying. Bat detectors are configured to be triggered by a high-frequency noise that is a certain threshold above the ambient noise. Once the high-frequency signal is detected (e.g. bat echolocation), the detector will record a sound file of the high-frequency noise until the signal is not detected for a defined amount of time (settings are configured by user; North American Bat Protocol for Bat Monitoring recommends 2 seconds) or the maximum file length has been reached (15s max file length recommended for bat monitoring). In this detector configuration each file is considered a “bat pass,” (Loeb et al 2015) while an individual pulse may be referred to as a “bat call” (Figure 1.4).

Bat acoustic monitoring is generally broken down into two types: active and passive monitoring. An active acoustic survey (also referred to as mobile survey) requires an acoustic monitoring device to record as a surveyor travels along a pre-determined route at approximately 20 miles per hour during fair-weather nights (little wind and rain). The surveyor can travel by vehicle or vessel, with vehicle travel being the most common method used to conduct mobile surveys. The length of active surveys will vary based on available routes to safely survey and will depend on the monitoring needs or research question. The speed at which the surveyor is travelling, allows each recorded bat pass to be considered an individual bat (Loeb et al. 2015). From these data, population trends can be calculated from repeated surveys across years (if surveys are conducted at approximately the same time each year). If mobile surveys are conducted multiple times throughout the year, seasonal differences in activity and abundance can be measured. Active acoustic surveys are biased toward detecting bat species that are more common and more commonly tend to use road-ways as flight paths. Active acoustic surveys often miss rare or more cryptic species (Coleman et al. 2014, Braun de Torrez et al. 2017).

Passive acoustic monitoring involves a bat detector placed at a stationary point and left to record with no user present. The length of time the acoustic monitor is left to record is determined by the monitoring needs or research question. Determining population trends is not possible using passive acoustic data. Unlike the active acoustic surveys, each bat pass cannot be considered an individual bat as a single individual may fly repeatedly over the bat detector throughout the night. Passive acoustic monitoring, instead, allows biologists to measure relative activity, and look at temporal and seasonal activity trends.

In addition to the number of bat passes indicating activity levels, an examination of call structure can also inform us about behavior. A foraging bat will generally have three parts to an echolocation sequence: search phase, approach phase, and terminal phase or feeding “buzz” (Figure 1.4). During the search phase, a bat is searching for prey in its environment by emitting pulses at a general rate of one pulse per wing beat (Griffin et al. 1960, Britton et al. 1997, Jones 1999). After the detection of an insect, the pulse rate increases to several pulses per wing beat allowing a bat to get closer to their prey without overlapping the pulse and echo; this change in pulse rate facilitates greater information retrieval (Britton et al. 1997, Kalko and Schnitzler 1989). At the end of the approach phase, a terminal buzz is emitted. A terminal buzz is a rapid succession of broadband pulses, giving the bat position information immediately before it attempts to capture its prey, that when made audible to the human ear resembles a “buzz” or “zip” sound (Fenton and Bell 1979).

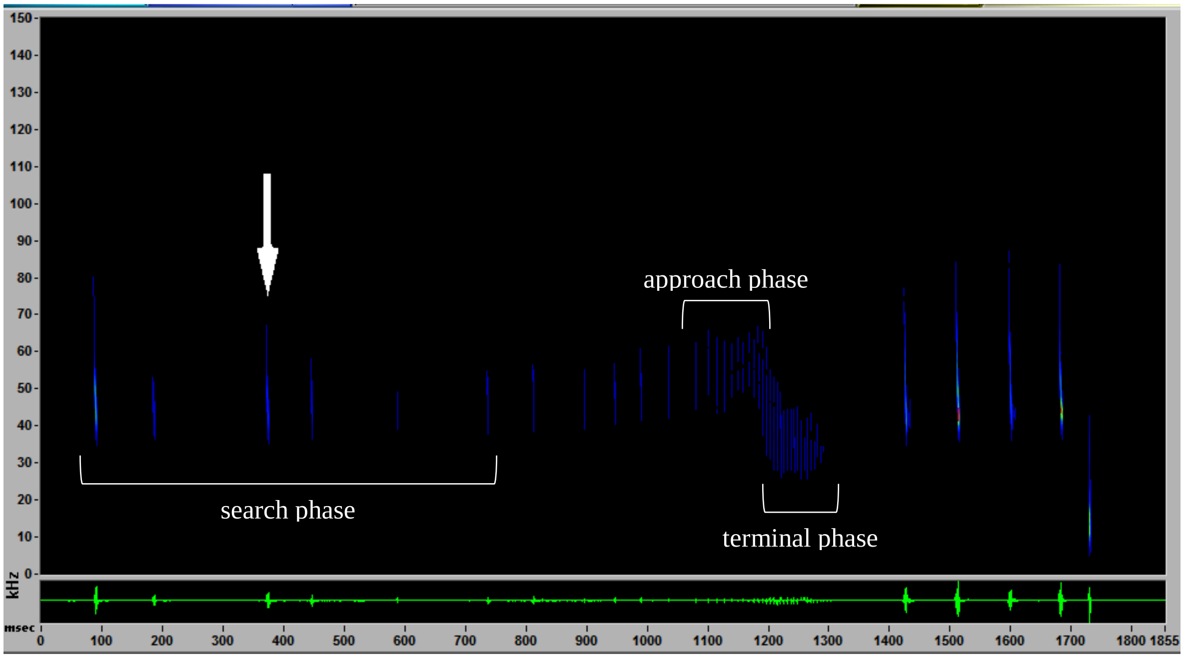


Figure 2.4 Spectrogram of a bat pass with the three phases of a bat call sequence: search phase, approach phase, and terminal phase or "feeding buzz." White arrow indicates an individual echolocation pulse.

Search phase pulses are used in species identification. Despite bats exhibiting major plasticity in their call structure (often sharing many call characteristics with other species), improvements in technology allow us to measure call parameters (e.g., minimum frequency, maximum frequency, duration) quantitatively and successfully attribute them to species using a combination of commercially available classifiers and manual identification based on the parameters (Fenton and Bell 1981, Obrist 1995, O'Farrell et al. 1999, Szewczak 2004, Britzke et al. 2011).

Summary

While the gameplay of golf has remained largely the same, golf course management has drastically evolved over the last half-century. Environmental impacts from intensive management activities have drawn criticisms from environmentalists and conservation biologists.

With more environmentally-friendly management practices that have been implemented on some golf courses over the last few decades, golf courses have the capacity to successfully support a variety of wildlife (especially more urban-adapted species). Using acoustical survey methods, this project aims to explore the relationship between bat activity on golf courses in Delaware.

Study Objectives

I. Examine the effects of five small-scale golf course landscape variables (water hazard, open grass, open understory managed, open understory natural, and dense understory natural habitats) on 1) overall bat activity, 2) bat foraging activity, 3) species richness and 4) species-specific activity using acoustical survey methods.

I predict that bat activity and richness will be higher in the open understory natural and dense understory natural habitats, as they more closely reflect the natural habitats that many species of bat prefer. I also predict that foraging activity will be highest at water hazard habitats, as the man-made ponds may have higher levels of insect activity for increased foraging opportunities.

Chapter III:

Research Methods

Site Selection

Four golf courses were chosen across Delaware using aerial imagery to identify courses had similar small-scale landscape characteristics (e.g. amount of wooded areas present on the course, number of water hazards). Once the prospective sites were chosen, I visited each golf course and met with the greenskeepers of each course to explain the project and request their involvement in the study. All golf courses queried agreed to be a part of the project: Deerfield Golf and Tennis Club (Newark, DE), Frog Hollow Golf Club (Middletown, DE), Garrisons Lake Golf Club (Smyrna, DE), and Sussex Pines Country Club (Georgetown, DE)

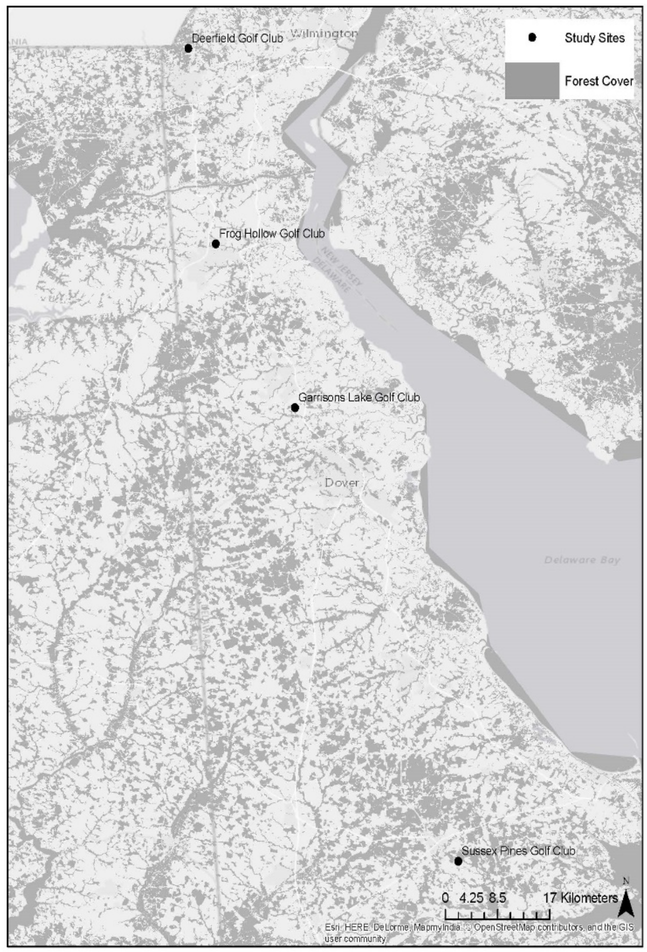


Figure 3.1. Map of the locations of golf courses used in the study Delaware, USA. Dark gray areas indicate forest cover and light gray areas indicate developed or agricultural land.

(Figure 3.1). The fours golf courses ranged in size from 62-139Ha, with an average size of 87.25Ha.

After establishing and visiting each golf course site I chose five visually distinguishable small-scale landscape areas to be studied (hereafter referred to as Habitats, Table 3.1), that were represented on all five courses: water hazard, open grass, open understory managed, open understory natural, and dense understory natural. Water hazards were defined as a man-made or natural water features. Open grass areas were areas where grasses grew mostly unmaintained (0.5-0.75m), but occasionally mowed (0.1m). Open understory managed areas were defined as areas where the ground was manicured in some way (mowed or mulched ground) often accompanied by a golf cart path and a closed high canopy cover with no understory, achieved by trimming low branches. Open understory natural areas were defined as forest fragments that were left to grow naturally and had a fairly open mid-understory. Dense understory natural areas were also forest patches left to grow naturally but tended to be younger forest patches with

Table 3.1 Habitat site description of habitats sampled at each golf course

Habitat	Description
Dense Understory Natural	Forest fragments that were left unmanaged and had a closed canopy with a cluttered understory
Open Grass	Tall grassed areas that were occasionally mowed but outside of the playing area.
Open Understory Managed	Ground was maintained (mowed and/or mulched) with a high closed canopy with an open understory obtained by pruning lower branches. Often times, golf cart paths ran through these areas
Open Understory Natural	Forest fragments that were left unmanaged with a closed canopy but more open understory than the Dense Understory Natural Habitat
Water Hazard	Man-made ponds on the golf course built to increase the difficulty of the game.

higher amounts of clutter in the low- to mid-understory. I chose these five areas as the main focus of the study because they are more representative of natural landscapes and can be more easily managed or altered than the already established fairways and greens on golf courses.

Acoustic Surveys

To capture the peak summer activity, in June and July of 2011, I visited one golf course a night for a total of 6 nights per golf course and placed a Wildlife Acoustics (Massachusetts, USA) SM2BAT bat detector (192kHz) paired with an omnidirectional SMX-US microphone at each microhabitat. Each microphone was positioned 2m off the ground with a metal conduit pole and angled at slightly less than 90° to prevent signal interference, capture as many bat passes as possible, and prevent microphone damage from unexpected rain events (Patriquin and Barclay 2003, Wildlife Acoustics SM2BAT User Manual). Surveys were only conducted on fair weather nights. I canceled surveys during heavy rain and high winds as both are known to affect bats' normal flight behavior (Voigt et al. 2011) and can reduce or permanently damage microphone sensitivity. Bat detectors were programed to begin recording at sunset and to record for four hours to capture the first peak of nightly bat activity (Hayes 1997). Detectors recorded full-spectrum files with a file length limit of 15 seconds. Files were compressed in the Wildlife Acoustics proprietary .WAC file format. Detector settings can be found in Table 2.2.

Bat echolocation files were processed using SonoBat™ (v. 3.8.6), a software specific for viewing, parameterizing and identifying recorded bat passes. To be included in the analysis, the recorded acoustic file containing a bat pass did not exceed 15s and contained a sequence of ≥ 2 bat echolocation pulses, separated by <1s (Fenton 1970). The number of files containing bat passes recorded each survey period (4-hour period after sunset) was used as an index of bat activity. Any recorded files that did not contain a bat pass were considered noise and removed from analysis (e.g. insect noise, electrical interference). Any night where the full period of recording did not occur (e.g. because of inclement weather or detector failure) was also removed from analysis.

All files containing a bat pass were visually inspected for the presence of feeding buzzes. The total number of feeding buzzes was recorded for each survey night at each habitat. If multiple feeding buzzes were present in one bat pass, all buzzes were included. The number of feeding buzzes recorded each survey period was used as an index of bat foraging activity.

Species were identified using the automated species identification algorithm feature of SonoBat 3.8.6. The automated classifier measures 72 different parameters from the recorded bat pulses (e.g. characteristic frequency – frequency at the flattest part of the pulse, frequency maximum and minimum, pulse duration, etc.). and makes an identification decision based on a reference library of known species call parameters using a discriminate probability function. All bat passes that were identified to a species were manually vetted to confirm that the software made a reasonable species choice. The elasticity of bat echolocation calls prohibits a single pulse to be used for species identification. To be included in the species-specific analysis, the recorded acoustic file containing a bat pass did not exceed 15s and contained a sequence of ≥ 3 bat echolocation pulses, separated by <1s (Fenton 1970). I used the reference library of known calls provided with SonoBat™ software along with guidance documents that described common bat call characteristics for identification (Humboldt State University Bat Lab 2011). Pulse shape, characteristic frequency, pulse duration, frequency maximum and minimum were the primary characteristics considered when vetting calls. Unidentified bat passes were labeled as “NoID.”

Given the plasticity of bat echolocation call structure and many factors affecting the quality of the recording (e.g., abiotic environmental conditions, bat flight directions, bat proximity to the microphone, etc.), identifying all recorded call files to a species level is not achievable (Reichert et al. 2018).

I quantified the following metrics per survey night (4-hour period) to evaluate the effect of habitat on bats using golf courses: 1) total activity levels (total number of files containing bat passes), 2) foraging activity (total number of feeding buzzes), 3) species-specific activity (total number of bat passes from each species), and 4) species richness (total number of species identified).

Table 3.2 Detector settings configured for the Wildlife Acoustics SM2BAT. Detectors were set based on recommendations from the Wildlife Acoustics SM2BAT User User Guide (https://www.wildlifeacoustics.com/images/documentation/Song-Meter-SM2Bat-Suppement.pdf)

Setting Name	Description	Setting
Analog HPF	Analog high pass filter. Preamplifier jumper setting that will filter out lower frequency noise and reduce non-bat noise.	1kHz
Analog Gain	Analog gain. Preamplified jumper setting that can increase the dynamic range and improve high-frequency signal-to-noise ratio and improve quality of recording loud high-frequency noises	+48dB
Sample Rate	Number of samples taken per second. Frequencies can be resolved up to half of the sample rate. Bats in the Delmarva Peninsula echolocate from a range of approximately 20kHz - 90kHz	192kHz
Digital HPF	Digital high pass filter. Digital setting that is 1/12 of the sample rate. Prevents detector from recording anything below the set frequency. Reduces recording of low frequency non-bat noise.	fs/12
TRG LVL	Trigger level. Recording begins when a signal in the set frequency range exceeds the threshold by 18dB	18SNR
TRG WIN	Trigger window. The length of time a signal needs to be absent to signal the end of recording. A setting of 2.0 seconds is recommended to consider each file a bat pass.	2.0s

I used the statistical program R (v.3.5.0, R Core Team 2018) with Rstudio (v.1.1.463 RStudio Team 2016) for all statistical analyses. I constructed generalized linear mixed effects models (GLMMs; function *glmer,* R package *lme4,* Bates et al. 2012) for each response variable (total activity, foraging activity, species-specific activity, and species richness per survey night) with habitat as a fixed effect and detector site nested within golf course as a random effect. I tested the effect of categorical predictors (i.e., golf course, habitat) by comparing 2 nested models (one with and one without the categorical variable) using a likelihood ratio test (LRT, function *anova*, R Stats package). I first tested for an effect of golf course on each response variable, but because it was not significant for most metrics, I included it as a random effect to account for any potential differences in activity across courses. If the categorical predictor variable was significant, I then used post-hoc Tukey contrasts for multiple comparisons to test pair-wise comparisons among the habitats with *p*-values adjusted with a Bonferonni correction (function *glht,* R package *multcomp*).

This modeling framework accounted for the non-independent observations of repeated survey nights at each detector site in each golf course (Braun de Torrez 2017). Standard diagnostics of the distribution of all response variables showed that the data was right skewed, therefore a Poisson distribution for count data was used in all models. A Poisson distribution was selected over a Gaussian distribution with a natural log transformation because Poisson is able to handle 0-values in the response variables (present in the foraging and several of the less common species-specific activity datasets).

Along with habitat, several combinations of biologically relevant temporal and spatial variables were included as covariates to determine the best model for predicting activity levels and species richness: mean temperature, mean humidity, mean wind speed, distance to closest water body, distance to the closest agricultural field. To determine the best model, I used the second order Akaike Information Criterion (AICc) for small sample sizes. If the difference between AICc values was ≤ 2, models were considered to be equivalent, and the model with the fewest parameters was chosen. To compare models, parameters were estimated using maximum likelihood and Laplace approximations (Bolker et al. 2009, Pinheiro et al. 2012).

Graphical analysis was performed in Microsoft Excel 2016.

Mist-netting

For further validation of bat species present at the golf courses, I used standard bat mist-netting techniques to physically capture bats at each golf course one time in 2010 and 2011. I used two sets of triple-high mist-net poles with 3 stacked 6meter mist-nets (Avinet, Inc.). The nets were placed non-randomly at locations on the golf course that were likely to improve capture rate (e.g. forested corridors with closed canopies, near sources of drinking water). Nets were opened 15 minutes before sunset and checked every 10-15 minutes for four hours. If a bat was captured, I documented the following demographic data: species, sex, age, reproductive status, weight, forearm length, and noted wing damage according the U.S. Fish and Wildlife's wing damage index (Reichard and Kunz 2009). Bat demographic data can indicate general health of the individual bats. Bats were released within 30-minutes of initial capture. After each mist-netting session, I decontaminated all mist-netting equipment following the most up-to-date U.S. Fish and Wildlife protocols, to prevent accidental spread of *Pd* (USFWS 2010).

Chapter IV:

Results

Acoustic Surveys

Each golf course was visited 6 times throughout June and July of 2011, but some nights were excluded from analysis because inclement weather (high winds, thunderstorms) or equipment failure prevented a full survey period from being recorded. A total of 272 detector hours were recorded (68 survey nights * 4 hours of recording/survey night) across all four courses (Deerfield Golf and Tennis Club, Frog Hollow Golf Club, Garrisons Lake Golf Club, Sussex Pines Country Club; Table 4.1). I visually inspected all recorded files to verify they contained a bat pass and removed any files that were considered noise (e.g. insect noise, electrical interference) from analysis. A total of 6899 (bat passes were recorded across all golf courses and habitats (Table 4.2).

Overall Bat Activity

The model that best explained overall bat activity (number of bat pass files per survey night) included habitat, mean temperature, mean humidity, and mean wind speed (Table 4.3, Table 4.4). In the pairwise comparisons, open understory managed habitat had significantly more bat activity (244.33 ± 72.92) than the open understory natural (43.7 ± 18.59; z = -3.32, p = 0.004) and open grass habitats (40.85 ± 15.11; z = 3.54 p = 0.002; Table 4.5 Figure 4.1A). No other pairwise comparisons were statistically significant.

Foraging Activity

The best model for predicting foraging activity (number of feeding buzzes per recording night) included both habitat and mean temperature (Table 4.3). Foraging activity significantly increased as temperature increased (Table 4.4). Pairwise comparisons showed significantly higher foraging activity in the open understory managed habitats (7.6 ± 2.82) than in the open grass (0.38 ± 0.18; z = 3.6,1 p = 0.002) and open understory natural (1 ± 0.49; z = -2.89, p = 0.03; Table 4.5, Figure 4.1B)

Table 4.*1 Total number of acoustic survey nights per golf course and habitat. Each golf course was visited 6 times through June and July 2011. Survey nights included in this table included nights where detectors recorded successfully for the full 4-hour survey period at all and/or some of the habitats. A "1" indicates a full survey night. A "0" indicates an incomplete survey night due to detector failure. Dates where surveys were canceled because of inclement weather were not included in this table.*

	Dense Understory Natural	*Open Grass*	*Open Understory Managed*	*Open Understory Natural*	*Water Hazard*	***Total Survey Nights***
Deerfield Golf Club						
6/20/2011	1	1	1	1	1	5
6/28/2011	1	1	0	1	1	4
7/13/2011	1	0	1	0	1	3
7/18/2011	1	0	1	1	1	4
Frog Hollow Golf Club						
6/22/2011	1	0	1	1	1	4
6/29/2011	0	1	1	1	1	4
7/15/2011	1	1	1	0	1	4
7/21/2011	1	1	1	0	1	4
7/27/2011	1	1	1	0	1	4
Garrisons Lake Golf Club						
6/17/2011	1	1	1	1	1	5
6/24/2011	1	1	1	1	1	5
7/6/2011	1	1	1	1	0	4
7/14/2011	1	1	1	0	0	3
7/26/2011		1	1	0	1	3
Sussex Pines Country Club						
6/23/2011	1	1	1	1	1	5
6/30/2011	1	1	0	1	1	4
7/12/2011	1	0	1	0	1	3
Total Survey Nights	15	13	15	10	15	68

Table 4.2 *Total bat activity and species-specific activity by habitat and by golf course. Total number of files and percentage of recorded files are reported. Species percentages represent total number of species-specific calls per the number of identified calls.*

	Total Bat Passes	*Total Identified to Species*	*Eptesicus fuscus*	*Lasiurus borealis*	*Lasiurus cinereus*	*Myotis lucifugus*	*Nycticieus humeralis*	*Perimyotis subflavus*
Golf Course								
Deerfield Golf Club	1532	698	400	152	26	7	62	51
		46%	57%	22%	4%	1%	9%	7%
Frog Hollow Golf Club	2450	1037	239	572	8	24	186	8
		42%	23%	55%	1%	2%	18%	1%
Garrisons Lake Golf Club	2385	1164	716	344	16	10	62	16
		49%	62%	30%	1%	1%	5%	1%
Sussex Pines Country Club	532	330	96	212	0	3	12	7
		62%	29%	64%	0%	1%	4%	2%
Total	6899	3229	1451	1280	50	44	322	82
		47%	45%	40%	2%	1%	10%	3%
Habitat								
Dense Natural	742	337	70	230	2	9	20	6
		45%	21%	68%	1%	3%	6%	2%
Open Understory Natural	437	186	74	70	1	2	30	9
		43%	40%	38%	1%	1%	16%	5%
Open Understory Managed	3665	1738	668	788	13	30	228	11
		47%	38%	45%	1%	2%	13%	1%
Open Grass	531	242	164	49	12	2	9	6
		46%	68%	20%	5%	1%	4%	2%
Water Hazard	1524	726	475	143	22	1	35	50
		48%	65%	20%	3%	0%	5%	7%
Total	6899	3229	1451	1280	50	44	322	82
		47%	45%	40%	2%	1%	10%	3%

Figure 4.3 *Selection of generalized linear mixed-effects models (GLMMs; Poisson distribution) to explain overall bat activity, foraging activity, species richness, and species-specific activity per survey night on golf courses in Delaware. For each activity dataset, the top three models are listed or only models with a total cumulative Akaike weight (ωi) ≥ 0.95 are listed. The top model selected was the model with the lowest AICc score. If the difference between AICc scores was ≤ 2, models were considered to be equivalent, and the model with the fewest parameters was selected. Categorical predictor variables are habitat (dense understory natural, open grass, open understory managed, open understory natural, and water hazard). Continuous predictor variables are mean temperature (mean temp), mean humidity, and mean wind speed (mean wind).*

Models (Bat Activity)	K	ΔAICc	ωi	Cumulative ωi
Overall Activity				
Habitat + Mean Temp + Mean Humidity + Mean Wind	10	0.00	1.00	1.00
Foraging Activity				
Habitat + Mean Temp + Mean Wind	9	0.00	0.40	0.40
Habitat + Mean Temp	8	0.73	0.28	0.68
Habitat + Mean Temp + Mean Humidity + Mean Wind	10	2.41	0.12	0.80
Species Richness				
Habitat	7	0.00	0.17	0.17
Null	3	0.19	0.33	0.33
Mean Wind	4	1.17	0.10	0.43
E. fuscus				
Habitat + Mean Temp + Mean Wind	9	0.00	0.54	0.54
Habitat + Mean Temp + Mean Humidity + Mean Wind	10	0.56	0.41	0.04
Habitat + Mean Temp + Mean Humidity	9	5.52	0.03	0.98
L. borealis				
Habitat + Mean Temp + Mean Wind	9	0.00	0.71	0.71
Habitat + Mean Temp + Mean Humidity + Mean Wind	10	1.77	0.29	1.00
L. cinereus				
Habitat + Mean Wind	8	0.00	0.23	0.23
Mean Humidity	4	0.26	0.20	0.43
Habitat	7	1.46	0.11	0.54
M. lucifugus				
Habitat + Mean Temp + Mean Wind	9	0.00	0.55	0.55
Habitat + Mean Temp + Mean Humidity + Mean Wind	10	1.49	0.26	0.82
Habitat + Mean Wind	8	3.32	0.11	0.92
N. humeralis				
Habitat + Mean Temp + Mean Humidity + Mean Wind	10	0.00	0.78	0.78
Habitat + Mean Temp + Mean Wind	9	2.53	0.22	1.00
P. subflavus				
Mean Humidity	4	0.00	0.93	0.93
Habitat + Mean Humidity	8	6.61	0.03	0.96

Figure 4.4 *Best generalized linear mixed-effect models (GLMMs; Poisson distribution) to explain bat activity and species richness per survey night on golf courses in Delaware reported. Categorical predictor variables are habitat (dense understory natural, open grass, open understory managed, open understory natural, and water hazard). Continuous predictor variables are mean temperature (mean temp), mean humidity, and mean wind speed (mean wind).*

Models	**K**	**Estimate**	**Std Error**	***p-value***
Overall Activity				
Habitat + Mean Temp + Mean Humidity + Mean Wind	10			
Intercept		1.03	0.44	0.0201
Mean Temperature		0.07	0.004	<0.001
Mean Humidity		0.54	0.1	<0.001
Mean Wind Speed		0.28	0.12	<0.001
Foraging Activity				
Habitat + Mean Temperature	9			
Intercept		-1.44	0.88	0.103
Mean Temperature		0.07	0.02	0.005
Species Richness				
Habitat				
Intercept	7			
		0.85	0.17	<0.001
E. fuscus				
Habitat + Mean Temperature + Mean Wind Speed	9			
Intercept		3.06	0.54	<0.001
Mean Temperature		-0.09	0.01	<0.001
Mean Wind Speed		0.11	0.04	0.003
L. borealis				
Habitat + Mean Temperature + Mean Wind Speed	8			
Intercept		-2.06	0.68	0.002
Mean Temperature		0.14	0.01	<0.001
Mean Wind Speed		0.29	0.04	<0.001
L. cinereus				
Mean Wind Speed	4			
Intercept		-2.56	0.76	<0.001
Mean Wind Speed		0.49	0.21	0.020
M. lucifugus				
Habitat + Mean Temperature + Mean Wind Speed	9			
Intercept		-5.68	1.74	0.001
Mean Temperature		0.13	0.05	0.013
Mean Wind Speed		0.62	0.21	0.002
N. humeralis				
Habitat + Mean Temp + Mean Humidity + Mean Wind	10			
Intercept		-7.57	1.06	<0.001
Mean Temperature		0.17	0.02	<0.001
Mean Humidity		1.23	0.53	0.021
Mean Wind Speed		0.73	0.09	<0.001
P. subflavus				
Mean Humidity	4			
Intercept		4.38	0.87	<0.001
Mean Humidity		-7.93	1.25	<0.001

Table 4.5 *Pairwise comparisons among habitats. If habitat was a significant predictor variable in the top GLMM, I used post-hoc Tukey contrasts for multiple comparisons with p-values adjusted with a Bonferonni correction. Only significant pairwise comparisons are included.*

	Estimate	Std. Error	*p*-value
Overall Activity			
Open Understory Managed - Open Grass	1.193	0.55	0.004
Open Understory Natural - Open Understory Managed	-1.81	0.55	0.008
Foraging Activity			
Open Understory Managed - Open Grass	3.01	0.83	0.003
Open Understory Natural - Open Understory Managed	-2.23	0.77	0.03
Species Activity			
Habitat not significant			
E. fuscus			
Open Managed Understory - Dense Natural	2.7	0.44	<0.001
Water Hazard - Dense Natural	2.09	0.44	<0.001
Open Managed Understory - Open Grass	1.65	0.42	<0.001
Open Understory Natural - Open Understory Managed	-2.2	0.43	<0.001
Water Hazard - Open Understory Natural	1.6	0.44	0.002
L. borealis			
Open Managed Understory - Open Grass	2.96	0.84	0.004
Open Understory Natural - Open Understory Managed	-2.45	0.84	0.029
L. cinereus			
Habitat not significant			
M. lucifugus			
Habitat not significant			
N. humeralis			
Habitat not significant			
P. subflavus			
Habitat not significant			

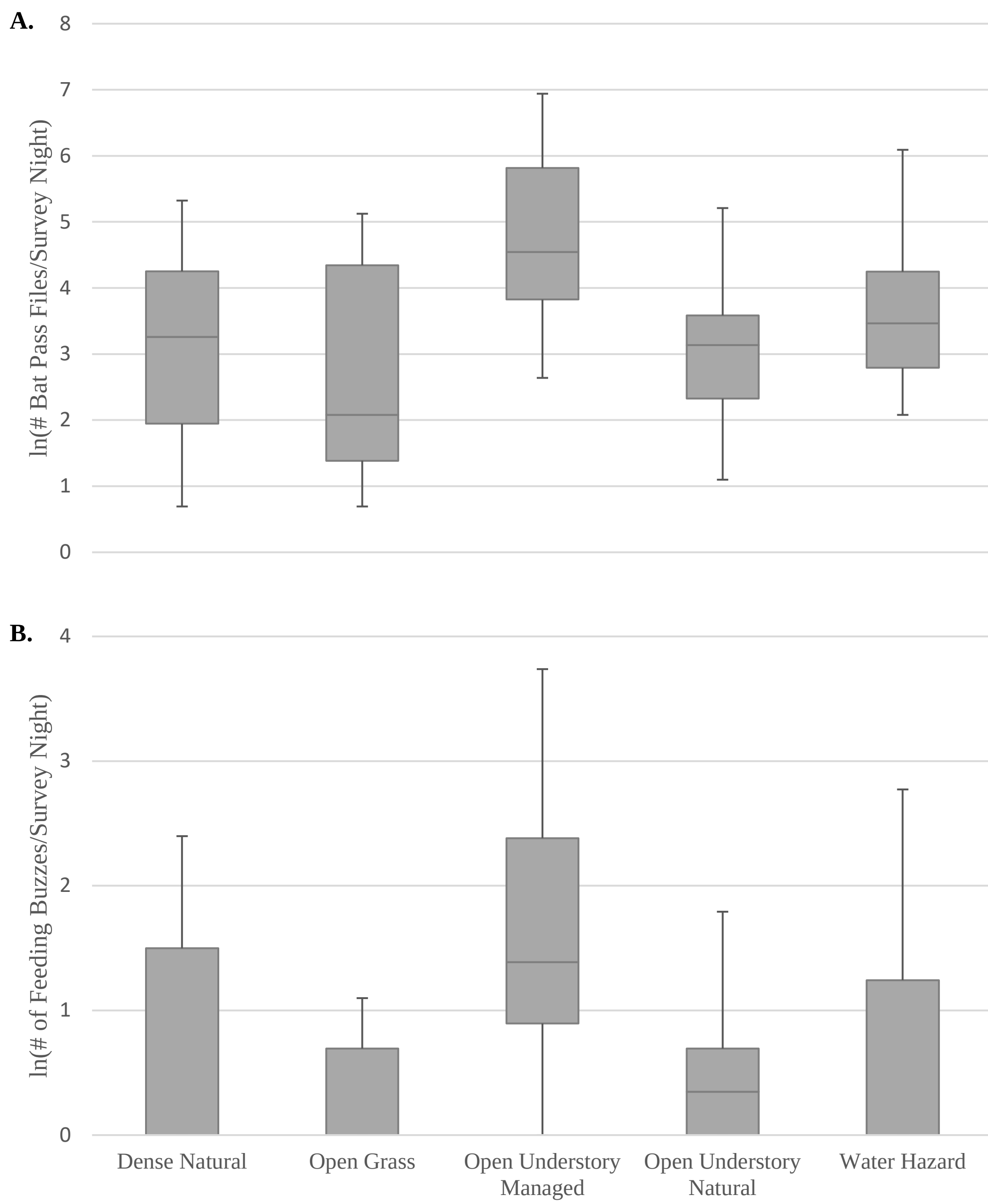


Figure 4.1 *Differences in A) overall bat activity (number of bat pass files per survey night) and B) foraging activity (# of feeding buzzes detected per survey night)) between habitats on golf courses in Delaware in June and July 2011. Y-axes are in the log scale.*

Species Richness and Species Composition

SonoBat (3.8.6) identified 46.8% (n = 3228) of all passes to a species and 53.2% (n = 3671) remained unidentified (NoID) (Table 4.2). Six species were identified from the files across all four golf courses and all habitats: *Myotis lucifigus* (little brown bat), *Eptesicus fuscus* (big brown bat), *Lasiurus borealis* (red bat), *L. cinereus* (hoary bat), *Nycticieus humeralis* (evening bat), and *Perimyotis subflavus* (tricolored bat).

The top model to explain species richness (number of species detected per survey night per detector) included only the categorical predictor habitat, but in pairwise comparisons there was not an effect of habitat. Six species were detected at every golf course, except for Sussex Pines Country Club where *L. cinereus* was not detected over any of the survey nights. The same six species were detected at every habitat type (Table 4.6).

Eptesicus fuscus and *L. borealis* were the most commonly identified calls for all golf courses and accounted for 45% and 40% of all identified calls, respectively (Table 4.2). *Nycticieus humeralis* accounted for 10% of the identified calls. *Lasiurus cinereus, M. lucifugus,* and *P. subflavus* were the least identified species across all golf courses with only 2%, 1%, and 3%, respectively, of the bat passes identified to those species (Table 4.2).

Lasiurus borealis was the most commonly identified species in the Dense Understory Natural habitat (68% of the identified calls) and Open Understory Managed habitat (45% of the calls; Figure 4.2). *Eptesicus fuscus* was the most commonly identified species in the Open Grass (68%) and Water Hazard (65%) habitats. In the Open Understory Natural habitat, *E. fuscus* and *L. borealis* made up approximately the same amount of the identified calls (40% and 38%, respectively). Occurring less frequently, *N. humeralis* was identified more often in the Open

Understory Natural and Open Understory Managed habitats (16% and 13% of identified calls) than in the other three habitat types. *Perimyotis subflavus*, *L. cinereus*, and, *M. lucifugus*, made up the smallest proportion of identified calls, ranging from 0.15% to 7% across species and

Table 4.6 Number of survey nights (4-hour survey period) each species was detected at each golf course and habitat type in Delaware in June and July 2011.

	E. fuscus	*L. borealis*	*L. cinereus*	*M. lucifugus*	*N. humeralis*	*P. subflavus*	Total Species Detected
Golf Course							
Deerfield Golf & Tennis Club	14	11	7	5	8	7	6
Frog Hollow Golf Club	17	11	4	4	7	4	6
Garrisons Lake Golf Club	17	16	5	6	10	8	6
Sussex Pines Country Club	11	9	0	2	7	1	5
Total	59	47	16	17	32	20	
Habitat							
Dense Natural	10	8	2	6	5	4	6
Open Grass	11	8	3	2	3	2	6
Open Understory Managed	15	15	6	6	12	6	6
Open Understory Natural	8	5	1	2	7	3	6
Water Hazard	15	11	4	1	5	5	6
Total	59	47	16	17	32	20	

habitat (Table 4.2, Figure 4.3)

Species Specific Activity

Eptesicus fuscus

The best model to explain *E. fuscus* activity included predictor variables of mean temperature, mean wind, and habitat (Table 4.3). Activity increased with a decrease in mean temperature and increase in mean wind speed (Table 4.4). Pairwise comparisons showed significant differences in habitat (Table 4.5). Open understory managed habitat had significantly higher *E. fuscus* activity (44.53 ± 13.14) than open understory natural (7.4 ± 2.97; z =-5.07, $p <$ 0.001), open grass (12.62 ± 4.02; z = 3.92, p <0.001), and dense understory natural habitats (4.67 ± 2.18; z = 6.11, $p < 0.001$, Table 4.3, Figure 4.3A). The water hazard habitat also had significantly more *E. fuscus* activity (31.67 ± 13.39) than the dense natural (4.67 ± 2.18; z =

4.73, p < 0.001) and open understory natural habitats (7.4 ± 2.97; z = 3.67, p = 0.002, Table 4.5, Figure 4.3A)

Lasiurus borealis

Habitat, mean temperature, and mean wind were included in the best model to predict activity levels of *L. borealis* (Table 4.3). In pairwise comparisons, activity was significantly higher at the open understory managed habitat (52.53 ± 19.03) than the open understory natural (7.00 ± 4.30; z = 2.92, p = 0.03) and open grass habitat (3.77 ± 2.48; z = 3.52, p = 0.003; Table 4.5, Figure 4.3B).

Lasiurus cinereus

Mean wind speed was the best predictor of *L. cinereus* activity (Table 4.3). Activity increased with mean wind speed (Table 4.4). In the pairwise comparisons, there were no significant differences in *L. cinereus* activity between habitats (Figure 4.3C).

Myotis Lucifugus

The best model for predicting activity of *M. lucifugus* was mean temperature, wind speed, and habitat (Table 4.3). However, in pairwise comparisons, the effect of habitat was not significant (Figure 4.3D).

Nycticeius humeralis

Habitat, mean temperature, mean humidity, and mean wind speed were included in the best model for predicting *N. humeralis* activity (Table 4.3). There was no significant effect of habitat on activity of *N. humeralis* (LRT, χ^2=5.76, df = 4, p = 0.218, Figure 4.3E).

Periomytois subflavus

The best predictor of *P. subflavus* activity was mean humidity (Table 4.3). There was no significant effect of habitat on activity of *P. subflavus* (LRT, χ^2=3.2, df = 4, p = 0.525, Figure 4.3F).

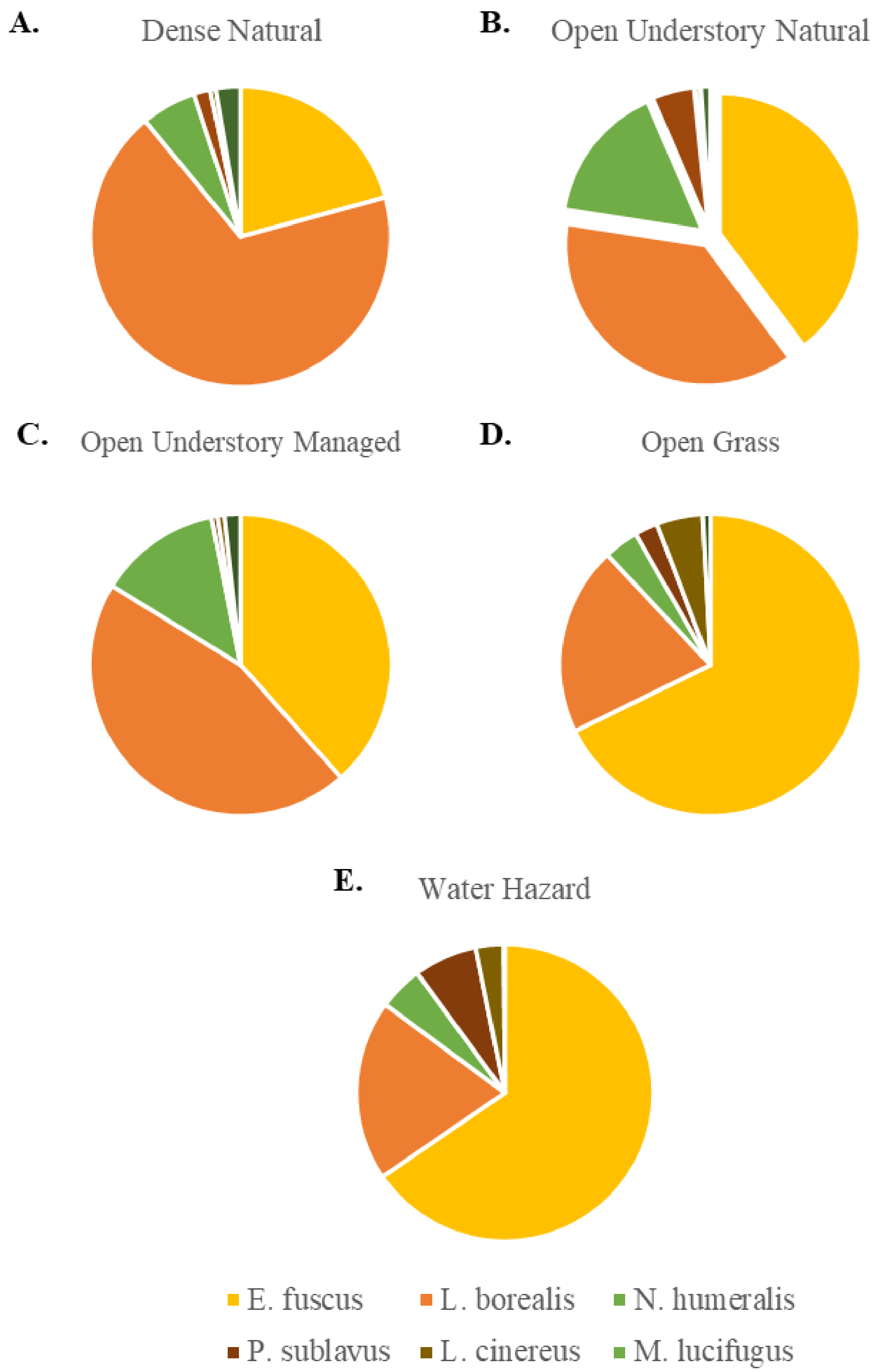


Figure 4.2 Species composition of identified bat passes between habitats on golf courses in Delaware recorded in June and July 2011. Six species were identified and detected in all five

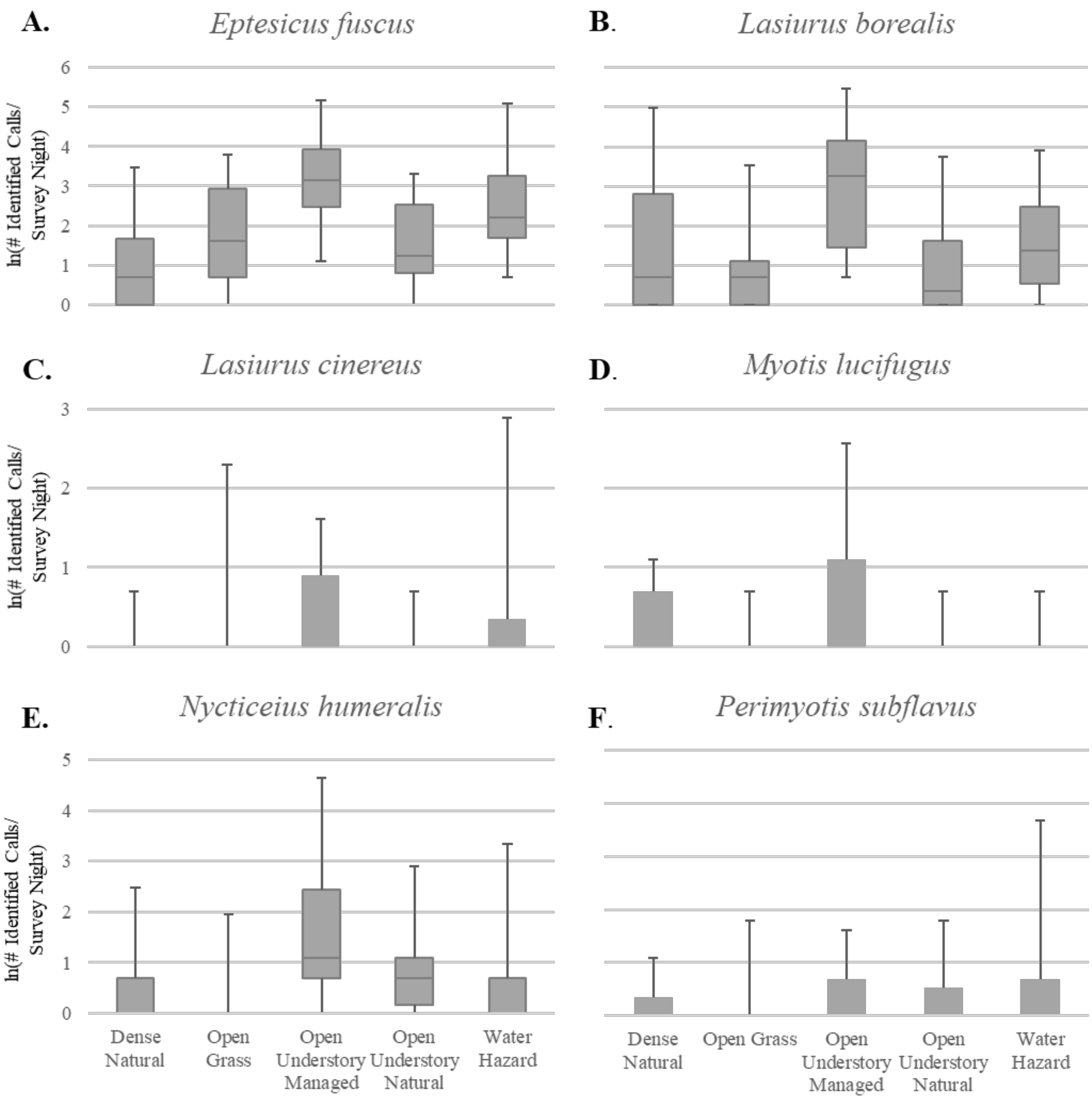


Figure 4.3 Differences in species-specific activity (number of identified calls per survey night) between golf course habitats recorded in Delaware in June and July 2011.Y-axes are in log scale.

Mist-Netting Surveys

Each golf course was netted with two triple-high 6m mist-net pole sets one time in 2010 and 2011 for a total of 192 net hours (6 6m nets * 4-hour net session * 8 nights) or 720 m^2 of net effort (6m net length * 2.5m net height * 3 nets per pole set * 2 pole sets * 8 net nights). Fifty-four bats were captured and fifty were able to be identified to species. Three species were identified: *E. fuscus, L.s borealis,* and *P. subflavus.* Four bats escaped from the net before an identification could be made.

Table 4.7 Species captured at each golf course in Delaware. Golf courses were mist-netted one time each in the summer of 2010 and 2011 for a total of 192 net hours or 720m² of net effort. Unknown (unknwn) bats were bats that escaped the mist-net before identification could be made.

Golf Course	Year	*E. fuscus*	*L. borealis*	*P. subflavus*	*Unknwn*	*Total*
Deerfield Golf and Tennis Club	2010	0	0	0	0	0
	2011	8	0	0	0	8
Frog Hollow Golf Club	2010	6	1	0	0	7
	2011	7	9	1	4	17
Garrisons Lake Golf Club	2010	3	2	0	0	5
	2011	2	4	0	0	6
Sussex Pines Country Club	2010	2	0	0	0	2
	2011	0	0	0	0	0

Chapter V:

Discussion

Effects of Golf Course Habitat on Overall Bat and Foraging Activity

In this study, I confirmed that many species of bats are using and foraging on a variety of habitats on golf courses in Delaware. Contrary to my predictions, significantly more bat activity occurred in the open understory managed habitats than the habitats the more closely reflected natural habitats (dense understory natural, open grass, and open understory natural). However, bats tend to use habitats that serve as flight corridors (e.g. hard tree line edges) and the open understory managed habitats provide vegetative structures that allow for easy flight (lack of low hanging branches) while offering some protection from potential predators by having an enclosed canopy (Agosta 2002, Hein 2009, Vaugh et al 1997, Wolcott and Vulinec 2012). Similarly, managed chestnut orchards (lack of dense undergrowth, closed canopy) in Switzerland had increased bat foraging activity and species richness compared to unmanaged chestnut orchards where the undergrowth was denser (Obrist et al. 2011). Also contrary to my predictions that the water hazard habitat would have the most foraging activity, foraging activity was highest in the open understory managed habitats. Foraging bats may also benefit from the insects disturbed by regular mowing of areas underneath this high canopy (Vandevelde et al. 2014).

Although in this study we did not sample non-golf course habitats, overall bat activity levels were comparable with other studies of regional habitats other than golf courses. In this study, we found 25.7 average passes/hour (This was calculated by dividing the total bat passes recorded by the 4-hour recording period), with a minimum of 0.25 and a maximum of 258 for all habitats. In Bombay Hook National Wildlife Refuge, one of the most undisturbed areas on the Peninsula, peak passes/hour were 140, with an average of around 5 passes/hour throughout the night (Fox 2007). McGowan and Hogue (2016) found an average of 65 passes/hour with active point-count transect surveys and 3.4 passes/hour for passive surveys. Wolcott and Vulinec (2012) found an average of 80.7 passes/hour combining recordings from the edges and in the middle of agricultural fields. However, these comparisons are limited and must be drawn carefully as the equipment used was different in all four studies. Different detectors and microphones have variable detection rates and can affect the variation in the amount and quality of the datasets (Adams et al. 2012). Additionally, only the Bombay Hook study (2007) and the passive detectors used by McGowan and Hogue (2016) looked at full nights. This study, Wolcott and Vulinec (2012), and McGowan and Hogue (2016) active transects examined peak activity time (directly after sunset for about 4 hours) therefore potentially overinflating nightly bat activity per hour measurements.

Other studies on golf courses documented similar diversity of bird species on golf courses as adjacent natural areas, but in lower numbers (Terman 1997). Birds and some insects showed higher species richness and abundance on golf courses than surrounding farmland (Tanner and Gange 2004). Higher insect abundance on golf courses may offer more foraging opportunities for bats.

Species Richness and Composition

Golf course or habitat did not have any significant effect on species richness per survey night. All six species were detected across all habitats and most golf courses (Sussex Pines lacked any identified detections of *L. cinereus*). This lack of effect is likely due to a small number of species in Delaware (8 species) and sampling occurring in a relatively small area (golf course size averaged 87.25ha). In this study, the species-richness metric did not consider relative activity levels as it only counted a species as present or absent on a given survey night. The species-specific activity levels may be a better indication of habitat use by each species.

The dominance of *E. fuscus* and *L. borealis* in the acoustic data set suggest either that they are more abundant than other species or are more commonly detected in urban and altered areas. Additionally, the calls of these species may be more easily detected and identified by acoustic survey methods. *Eptesicus fuscus* and *L. borealis* had the highest activity levels in the open understory managed habitat. In addition to attractive flight corridors, these large-boled trees in this habitat may provide roosting opportunities (e.g., leaf clusters in hardwoods for *L. borealis* or tree cavities for *E. fuscus*) Mist-netting captures from the golf courses corroborate that *E. fuscus* and *L. borealis* may be more abundant or commonly caught in these areas (Sturgis and Vulinec, unpublished).

The observed lower presence of other species may be explained by life history differences or by limitations of our survey methods. Lower acoustic detection and capture rates of the cave bat species (*M. lucifugus, P. subflavus*) may be because of regional population declines due to white nose syndrome (Ford et al. 2011). The endangered *Myotis septentrionalis* is an uncommon species in Delaware, restricted to the northern portions of the state, and was not identified in any of the recorded calls. The lack of detection of *Lasionycteris noctivigans* is not surprising given that it has been rarely documented in Delaware.

The lack of observable effect of habitat on some species activity (*L. cinereus, M. lucifugus, N. humeralis,* and *P. subflavus*) may be a lack of preference for these species. However, trends of greater use in some habitats were observed, and the lack of effect is more likely the result of small sample size.

Mist-net and acoustical sampling each have their own biases and are best when used in conjunction with one another (Kuenzi and Morrison 1998, O'Farrell and Gannon 1999). Mist-netting capture often misses high-flying bat species (e.g., *L. cinereus or L. noctivigans*). Acoustical sampling methods frequently miss quiet echolocating (low intensity) bat species that typically glean insects from trees (e.g. *M. septentrionalis*). In this study, mist-netting on golf courses typically occurred in areas along hard tree line edges that served as bat flight corridors. Water sources are ideal locations to catch other bats not typically caught in nets because even high-flying bats need to drink water but netting over water was largely avoided in this study due to logistics of setting mist-nets over deep-water hazards. Catching only three species (*E. fuscus, L. borealis*¸ and *P. subflavus*) across the golf courses was not unexpected given the habitats sampled and inherent mist-netting biases. Mist-netting in combination with acoustic sampling may not be as important in areas, such as Delaware, where species diversity is relatively low. Netting is nevertheless often recommended because it allows researchers to collect demographic and general body condition data that is not possible to assess through acoustical methods alone

Explaining the Effect of Climatic Variables on Bat Activity

While the purpose of my study was to look at the effect of golf course habitat on bat activity, I included biologically relevant environmental variables as covariates to account for variation in bat activity. Mean temperature was an important covariate in predicting overall activity, foraging activity, and species-specific activity of *E. fuscus, L. borealis, M. lucifugus,* and *N. humeralis*. All the relationships were positive, except for *E. fuscus*, whose activity levels increased as mean temperature decreased. Positive relationships between temperature and bat activity are well documented in the literature (Hayes 1997, Erickson and West 2002, Agosta et al. 2005, Wolbert et al 2014). Low temperatures are generally associated with decreased insect activity (Mellanby1939). Decreased activity of the bats' food source (insects) may result in lower activity levels of bats as they choose to forage for a shortened period of time or not at all (Anthony et al 1981). In this study, I conducted surveys only in June and July when temperatures are relatively warm and stable and should not result in significantly reduced levels of insect activity.

One initially puzzling result from this study was the positive relationship between mean wind speed and bat activity. Mean wind speed was an important factor in predicting overall activity and activity of *E. fuscus*, *L. cinereus*, *M. lucifugus*, and *N. humeralis.* Increased wind speeds are typically associated with decreased bat activity as it increased the difficulty of flight (O'Farrell and Bradley 1970, Verboom and Spoelstra 1999). However, Verboom and Spoelstra (1999) found increased activities of bats along treelines during times of high winds. In this study, mean wind speed was not taken directly at each habitat, rather from a nearby weather station to indicate overall weather patterns rather than site specific metrics. I suggest that bats may be using the treelined edges of the open understory managed habitats as protected flight corridors during times of increased wind speeds.

Conservation Implications

This study highlights the conservation potential of highly disturbed habitats, golf courses, to function as alternative habitats for bats. In particular, open understory managed habitats had higher overall bat activity, foraging activity, and some species-specific activity, indicating that this habitat is a feature that bats are using more than other habitats on the golf courses in

Delaware. Rather than being barren of wildlife, golf courses can be opportunities to conserve and protect animals if managed appropriately. Based on my data, I suggest two management options that may encourage bat activity on golf courses. I suggest:

1) Stands of large-boled trees with maintained undergrowth, i.e. grass and trimmed lower tree limbs, are favored by bats for commuting and foraging. These areas also allow golf cart passage and are attractive and park-like to many people. These areas should be kept as maintained wooded areas, and minimal pesticide use should be encouraged

2) Water hazards provide a source of drinking water for bats but may also present problems. Pesticide and fertilizer run-off from the course turf may decrease water quality and be potentially harmful to imbibing animals. In light of this, it is recommended golf course managers attempt to ensure proper pesticide application to minimize run-off. Greenskeepers and golf course managers already do this on many courses, but this study adds bat conservation as another important reason to continue these practices.

Although not addressed in this study, other management options that may promote bat use of golf courses include:

1) Leaving patches of forest may afford bats increased potential of day roosts (Limpert et al. 2007) and for golfers, heighten the challenge of the game.

2) Creating and maintaining a golf course with more heterogeneous landscapes may increase bat diversity on a golf course by providing landscape features that are attractive to certain species.

As more golf courses expand over the globe, similar measures can be tailored to the biome and local ecosystem so that golf courses can provide conservation opportunities for numerous wildlife species. While developed and maintained landscapes are not a substitute for natural habitat, some of these disturbed areas can be beneficial to bats. Similar to peregrine falcons (*Falco peregrinus*) and other wildlife living in urban and suburban landscapes, many bat species can adapt to human landscaping. Patches of forest and buildings may serve as roosts and, as we have shown in this study, even heavily maintained parts of golf courses can provide foraging and commuting opportunities for bats.

This study was restricted to Delaware and was small in scope but is the first to examine bat activity on golf courses and serves as a first step in understanding bat habitat use on these landscapes. While open understory managed habitats had the highest overall bat and foraging activity, I did not compare these to non-golf course habitats. I suggest additional research in comparative acoustic surveys in habitats on and off golf courses with an increased amount of survey nights and expanded time frame to be able to also look at seasonal differences in activity. Additional studies to locate day-roosts of bats captured on golf courses can increase our knowledge of how bats are using golf courses as habitat (i.e., feeding, commuting, and/or roosting). Diet studies of bats captured on the golf course may also provide insight on what insects (especially turf grass pests) bats are eating on golf courses and be helpful in determining the economic value of bats as pest control agents to greenskeepers and golf course managers. This study, in addition to further research, opens the door for golf courses to mitigate some of the effects of habitat loss and fragmentation on bat populations.

.

References

Adams AM, Jantzen MK, Hamilton RM, and MB Fenton. 2012. Do you hear what I hear? Implications of detector selection for acoustic monitoring of bats. *Methods in Ecology and Evolution*. 3(6):992-998.

Agosta SJ. 2002. Habitat use, diet and roost selection by the big brown bat (*Eptesicus fuscus*) in North America: a case for conserving an abundant species. *Mammal Review*. 32(2): 179-198.

Agosta SJ, Morton D, Marsh BD, and KM Kuhn. 2005. Nightly, seasonal, and yearly partterns of bat activity at night roosts in the central Appalachians. *Journal of Mammalogy*. 86:1210-1219.

Anthony, ELP and Kunz, T.H. 1977. Feeding strategies of little brown bat, *Myotis-Lucifugus*, in southern New-Hampshire. *Ecology*. 58: 775-786.

Anthony ELP, Stack MH and TH Kunz. 1981. Night roosting and the nocturnal time budget of the little brown bat *Myotis lucifugus*: effects of reproductive status, prey density, and environmental conditions. *Oecologia*. 51: 151-156

Attorney General Office of New York State. 1991. Toxic fairways: risking groundwater contamination from pesticides on Long Island golf courses. State of New York Department of Law. Environmental Protection Bureau.

Baerwald EF, D'Armours GH, Klug BJ, and RMR Barclay. 2008. Barotrauma is a significant cause of bat fatalities at wind turbines. *Current Biology*. 18(16): 695-696.

Barclay RMR, Faure, PA, and DR Farr. 1988. Roosting behavior and roost-selection by migrating silver haired bats (*Lasionycteris noctivagans*). *Journal of Mammalogy*. 69: 821–825.

Barton, J. 2008**.** How green is golf? https://www.golfdigest.com/story/environment_blackwelder

Bates D, Maechler M, and B Bolke r. 2012. lme4: linear mixedeffects models using S4 classes. R package version 0.999999-0. http://CRAN.R-project.org/package=lme4.

Belwood JJ and MB Fenton. 1976. Variation in the diet of *Myotis lucifugus* (Chiroptera: Vespertilionidae). *Canadian Journal of Zoology*. 54(1): 1674-1678.

Black HL. 1974. A north temperate bat community: structure and prey populations. *Journal of Mammology*. 55(1): 138-157.

Blehert DS, Hicks AC, Behr M, Meteyer CU, Belowski-Zier BM, Buckles EL, Coleman JTH, et al. 2009. Bat white-nose syndrome: an emerging fungal pathogen? *Science*. 323(5911): 227.

Bolker, B. M, Brooks, ME, Clark CJ, Geange SW, Pousen JR, Stevens MHM, and JS White. 2009. Generalized linear mixed models: a practical guide for ecology and evolution. *Trends in Ecology and Evolution* 24:127–135.

Boyles JG, Cryan PM, McCracken GF, and TH Kunz. 2011. Economic importance of bats in agriculture. *Science*. 332: 41-42.

Braun de Torrez, EC, Ober HK, and RA McCleery. 2017. Critically imperiled forest fragment supports bat diversity and activity within a subtropical grassland. *Journal of Mammalogy*, 99(1), 273-282.

Brigham RM., et al., eds. 2004. Bat echolocation research: tools, techniques and analysis. Bat Conservation International. Austin, Texas.

Britton ARC, Jones G, Rayner JMV, Boonman AM, and B. Verboom. 1997. Flight performance, echolocation and foraging behavior in pond bats, *Myotis dasycneme* (Chiroptera: Vespertilionidae). *Journal of Zoology*. 241(3): 503-522.

Britzke ER, Duchamp JE, Murray KL, Swihart RK, and LW Robbins. 201. Acoustic identification of bats in the eastern united states: a comparison of parametric and nonparametric methods. *Journal of Wildlife Management*. 75(3): 660-667.

Capparella A, Loew S, and DK Meyerholz. Ecology: bat deaths from wind turbine blades. *Nature*. 2012 Aug 2;488(7409):32.

Chamberlain S, 1995. Golf endangers Hawaiian ecology and culture. *Earth Island Journal*. Summer.

Chatterjee P, 1993. Clubbing Southeast Asia: the impacts of golf course development. *Multinational Monitor*. November. Available at: https://multinationalmonitor.org/hyper/issues/1993/11/mm1193_13.html

Cleveland CJ, Betke M, Federico P, et al. 2006. Economic value of the pest control service provided by Brazilian free-tailed bats in south-central Texas. *Frontiers in Ecology and the Environment*. 4(5): 238-243.

Colding J, and C Folke. 2009. The role of golf courses in biodiversity conservation and ecosystem management. *Ecosystems*. 12: 191-206.

Coleman LS, Ford WM, Dobony CA, and ER Britzke. 2014. A comparison of passive and active acoustic sampling for a bat community impacted by white-nose syndrome. *Journal of Fish and Wildlife Management*. 5(2): 217-226.

Cornell KL, Kight CR, Burdge RB, et al. 2011. Reproductive success of eastern bluebirds (*Siala sialis*) on suburban golf courses. *The Auk*. 128(3): 588-586.

Coutts RA, Fenton MB and E Glen. 1973. Food intake by captive *Myotis lucifugus* and *Eptesicus fuscus* (Chiroptera: Vespertilionidae). *Journal of Mammology*. 54: 985-990

Cox C. 1991. Pesticides on golf gourses: mixing toxins with play? *Journal of Pesticide Reform*. 11(3): 2-4.

Cryan PM. 2003. Seasonal distribution of migratory tree bats (*Lasiurus* and *Lasionycteris*) in North America. *Journal of Mammology*. 84(2): 579-593.

Cryan PM and RMR Barclay. 2009. Causes of bat fatalities at wind turbines: hypotheses and predictions. *Journal of Mammology*. 90(6): 1330-1340.

Cryan PM, Meteyer CU, Lorch DS, Reeder DM, Turner GG, Webb J, Behr M, Verant M, Russell RE, and KT Castle. 2013. Electrolyte depletion in white-nose syndrome bats. *Journal of Wildlife Diseases*. 49(2): 398-402.

Czech B. 2000. Technological progress and biodiversity conservation: a dollar spent, a dollar burned. *Conservation Biology*. 17(5): 1455-1457

Czech B, Krausman PR, and PK Devers. 2000. Economic associations among causes of species endangerment in the United States. *Bioscience*. 50: 593-601.

Edmondson J. 1987. Hazards of the game. *Audubon*. November: 25-37.

Erickson JL and SD West. 2002. The influence of regional climate and nightly weather conditions on activity patterns of insectivorous bats. *Acta Chiropterologica*. 4(1): 17-24.

Failey EL, McCoy JC, Price SJ and ME Dorcas. 2007. Ecology of turtles inhabiting golf course and farm ponds in the western Piedmont of North Carolina. *Journal of North Carolina Academy of Science*. 123: 221-232.

Feldhammer GA, Carter TC, and JO Whitaker Jr. 2009. Prey consumed by eight species of insectivorous bats from southern Illinois. *American Midland Naturalist*. 162(1): 43-51.

Fenton MB. 1970. A technique for monitoring bat activity with results obtained from different environments in southern Ontario. *Canadian Journal of Zoology*. 48:847-851.

Fenton MB, Jacobson SL, and RN Stone. 1973. An automatic ultrasonic sensing system for monitoring the activity of some bats. *Canadian Journal of Zoology*, 51: 291-299

Fenton MB and GK Morris. 1976. Opportunistic feeding by desert bats (*Myotis* spp). *Canadian Journal of Zoology*. 54(4): 526-530.

Fenton MB and GP Bell. 1979. Echolocation and feeding behavior in four species of *Myotis* (Chiroptera). *Canadian Journal of Zoology* 57(6): 1271-1277.

Fenton MB and GP Bell. 1981. Recognition of species of insectivorous bats by their echolocation calls. *Journal of Mammology.* 62(2): 233-243

Flaquer C, Torre I, and A Arrizabalaga. 2007. Comparison of sampling methods for inventory of bat communities. Journal of Mammalogy. 88(2): 526-533.

Ford WM, Britzke ER, Dobony CA, Rodrigue JL, and JB Johnson. 2011. Patterns of acoustical activity of bats prior to and following white-nose syndrome occurrence. *Journal of Fish and Wildlife Management*. (2):125-34.

Fox M. 2007. Bat species occurrence and habitat use at Bombay Hook National Wildlife Refuge. MS Thesis. Delaware State University, Dover, DE. 117pp.

Frick WF, Pollock JF, Hicks AC, Langwig K, Reynolds DS, Turner GG, Butchowski C, and TH Kunz. 2010. A once common bat faces rapid extinction in the northeastern United States from a fungal pathogen. *Science*. 329: 679-682.

Fry M. 1995. Reporoductive Effects in birds exposed to pesticides and industrial chemicals. *Environmental Health Perspectives*. 103(7): 165-171

Futures Company for HSBC. 2012. Golf's 2020 Vision: The HSBC Report. 1-52.

Golf Course Superintendents Association of America (GCSAA). 2007. Property profile and environmental stewardship of golf courses. *Golf Course Environmental Profile.* Phase I, Volume I.

Golf Course Superintendents Association of America (GCSAA). 2012. Pesticide use on U.S. golf courses. *Golf Course Environmental Profile.* Phase I, Volume V

Golf Course Superintendents Association of America (GCSAA). 2017. Land use characteristics and environmental stewardship programs on U.S. golf courses. *Golf Course Environmental Profile.* Phase II, Volume IV.

Gore JA, Robson MS, Zambrano R. and NJ Douglass. 2015. Roosting sites of a Florida bonneted bat (*Eumops floridanus*). *Florida Field Naturalist*. 43(4): 179-184.

Griffin DR, Webster FA, and CR Michael. 1960. The echolocation of flying insects by bats. *Animal Behavior.* 8:141-154.

Grodsky SM, Behr MJ, Gendler A, Drake D, Dieterle BD, Rudd RJ, and NL Walrath, 2011. Investigating the causes of death for wind turbine-associated bat fatalities. *Journal of Mammalogy.* 92(5): 917-925

Grue CE. 1982. Response of common grackles to dietary concentrations of four organophosphate pesticides. *Archives of Environmental Contamination and Toxicology*. 11: 617-626

Gruver JC. 2002. Assessment of bat community structure and roosting habitat preferences for the hoary bat (*Lasiurus cinereus*) near Foote Creek Rim, Wyoming. M.S. Thesis. University of Wyoming, Laramie, Wyoming.

Haith DA and MW Duffany. 2007. Pesticide runoff loads from lawns and golf courses. *Journal of Environmental Engineering*. 133(4):435-46.

Harvey MJ, Altenbach JS, and TL Best. 2011. Bats of the United States and Canada. 1st Edition. John Hopkins University Press. Baltimore, Maryland. 202pp.

Hayes, JP. 1997. temporal variation in activity of bats and the design of echolocation-monitoring studies. *Journal of Mammology*. 78(2): 514-524.

Hayes MA. 2013. Bats killed in large numbers at United States wind energy facilities. *BioScience.* 63(12): 975-979.

Hein CD, Castleberry SB, Miller KV. 2009. Site-occupancy of bats in relation to forested corridors. *Forest Ecology and Management*. 257:1200-1207.

Henderson JD, Yamamoto JT, Fry DM, Seiber JN, and BW Wilson. 1994. Oral and dermal toxicity of organophosphate pesticides in the domestic pigeon (*Columba livia*). *Bulletin of Environmental Contamination and Toxicology*. 52: 633-640.

Hodgkison SC, Hero J-M, and J. Warnken. 2007. The conservation value of surburban golf courses in a rapidly urbanising region of Austrailia. *Landscape and Urban Planning*. 79: 323-337.

Horn JW, Arnett EB, and TH Kunz. 2008. Behavioral responses of bats to operating wind turbines. *Journal of Wildlife Management*. 72(1): 123-132.

Humboldt State University Bat Lab. 2011. Echolocation Call Characteristics of Eastern US Bats. Available at: http://www.sonobat.com/download/EasternUS_Acoustic_Table_Mar2011.pdf

Hurriaga R. 1995. Tepoztlán: colisión de cosmovisiones. *La Jornada*. 22 September, 1995.

Jones G. 1999. Scaling of echolocation call parameters in bats. *The Journal of Experimental Biology*. 202: 3359-3367.

Jones G, Jacobs DS, Kunz TH, Willig MR, and PA Racey. 2009. Carpe noctem: the importance of bats as bioindicators. *Endangered Species Research.* 8: 93-115.

Kalcounis-Ruppell MC, Psyllakis JM, and RM Brigham. 2005. Tree roost selection by bats: an empirical synthesis using meta-analysis. *Wildlife Society Bulletin*. 33(3): 1123-1132.

Kalko EKV, and HU Schnitzler. 1989. The echolocation and hunting behavior of Daubenton's bat, *Myotis daubentoni*. *Behavioral ecology and sociobiology*. 24(4): 225-238.

Kendall RJ, Brewer LW, and RR Hitchcock. 1993. Response of Canada geese to a turf application of Diazinon AG500. *Journal of Wildlife Diseases.* 29(3): 458-464.

Knopper LD, and DRS Lean. 2004. Carcinogenic and genotoxic potential of turf pesticides commonly used on golf courses. *Journal of Toxicology and Environmental Health*. Part B. 7(4): 267-279.

Kross BC, Burmeister LF, Ogilvie LK, Fuotes LJ and CM Fu. 1996. Proportional mortality study of golf course superintendents. *American Journal of Industrial Medicine.* 29(5): 501-506.

Krusic RA, and CD Neefus. 1996. Habitat associations of bat species in the White Mountain National Forest. Pp. 185-198 in Bats and forests symposium (R. M. R.Barclay and R. M. Brigham, eds.). British Columbia Ministry of Forests, Victoria, British Columbia, Canada.

Kuenzi AJ, and ML Morrison. 1998. Ultrasonic sensors. *Wildlife Society Bulletin.* 26(2): 307-311.

Kunz TH. 1982. Roosting ecology of bats. in *Ecology of bats.* Spring US. Chapter 1: 1-55.

Kunz TH, Whitaker JO, and MD Wadanoli. 1995. Dietary energetics of the insectivorous Mexican free-tailed bat (*Tadarida brasiliensis*) during pregnancy and lactation. *Oecologia*. 101:407-415.

Kunz TH, Arnett EB, Cooper BM, Erickson WP, Larkin RP, Mabee T, Morrison ML, Strickland MD, and JM Szewcak. 2007a. assessing impacts of wind-energy development on nocturnally active birds and bats: a guidance document. *Journal of Wildlife Management.* 71(8): 2449-2486.

Kunz TH, Arnett EB, Erickson WP, Hoar AR, Johnson GD, Larkin RP, Strickland MD, et al. 2007b. Ecological impacts of wind energy development on bats: questions, research needs, and hypotheses. *Frontiers in Ecology and the Environment*. 5(6): 315-324.

Kurta A, Bell GP, Naga KA, and TH Kunz. 1989. Energetics of pregnancy and lactation in freeranging little brown bats (*Myotis lucifugus*). *Physiological Zoology*. 62(1): 804-818.

Kuvan, Y. 2005. The use of forests for the purpose of tourism: the case of Belek Tourism Center in Turkey. *Journal of Environmental Management*. 75(3): 263-274.

Kuvan, Y. 2010. Mass tourism development and deforestation in Turkey. *Anatolia*. 21(1): 155-168.

LeClerc JE, Che JP, Swaddle JP, and DA Cristol. 2005. Reproductive success and developmental stability of eastern bluebirds on golf courses: evidence that golf courses can be productive. *Wildlife Society Bulletin*. 33(2): 483-493.

Limpert DL, Birch DL, Scott MS, et al. 2007. Tree selection and landscape analysis of eastern red bat day roosts. *Journal of Wildlife Management*. 71(2): 478-486.

Loeb SC, Rodhouse TJ, Ellison LE, Lausen CL, Reichard JD, Irvine KM, Ingersoll TE, Coleman JTH, Thogmartin WE, Sauer JR, Francis CM, Bayless ML, Stanley TR, and DH Johnson. 2015. A plan for the North American Bat Monitoring Program (NABat). Gen. Tech. Rep. SRS-208. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 100p.

Lorch JM, Meteyer CU, Behr M, Boyles JG, Cryan PM, Hicks AC, Ballmann AE, et al. 2011. Experimental infection of bats with *Geomyces destructans* cause white-nose syndrome. *Nature*. 00(000): 1-4.

Lorch JM, Palmer JM, Lindner AE, Ballmann AE, George KG, Griffin K, Knowles S, Huckabee JR, Haman KH, Anderson CD and PA Becker. 2016. First detection of bat white-nose syndrome in western North American. *MSphere*. 1(4): e00148-16.

Maine JJ and JG Boyles. 2015. Bats initiate vital agroecological interactions in corn. *Proceedings of the National Academy of sciences*. 112(40): 12428-12443.

Marcot, BG. 1996. An ecosystem context for bat management: a case study of the Interior Columbia River Basin, USA. In *Bats and forests symposium, Canada Research Branch, BC Ministry of Forestry, Victoria* (pp. 19-36).

Marzluff JM. 2001. Worldwide urbanization and its effects on birds, in: Marzluff JM, Bowman R, and Donnelly R (eds.) *Avian Ecology and Conservation in an Urbanizing World*. Springer US. Section 1: 19-47.

McGowan AT and AS Hogue. 2016. Bat occurrence and habitat preference on the delmarva peninsula. *Northeastern Naturalist*. 23(2): 259-276.

McIntyre NE, Rango J, Fagan WF, and SH Faeth. 2001. Ground arthropod community structure in a heterogeneous urban environment. *Landscape and Urban Planning.* 52(12): 257-274.

McKinney ML. 2002. Urbanization, Biodiversity, and Conservation. *Bioscience*. 52(10): 883-890.

Mellanby K. 1939. Low temperature and insect activity. *Proceedings of the Royal Society*. 127(849): 473-487

Miller B. 2001. A method for determining relative activity of free flying bats using a new activity index for acoustic monitoring. *Acta Chiropterologica.* 3(1): 93-105.

Mitra A, Chatterjee C, and FB Mandal. 2011. Synthetic chemical pesticides and their effects on birds. *Research Journal of Environmental Toxicology*. 5: 81-96.

Morris AD, Miller DA, and MC Kalcounis-Rueppell. 2010. Use of forest edges by bats in a managed pine forest landscape. *Journal of Wildlife Management*. 74(1): 26-34.

Norberg UM, and JMV Rayner. 1987. Ecololgical morphology and flight in bats (Mammalia: Chiroptera): wing adaptations, flight performance, foraging strategy and echolocation. *Philosophical Transactions of the Royal Society of London B, Biological Science*. 316(1179):335-427.

Obrist MK. 1995. Flexible bat echolocation: the influence of individual, habitat, and conspecifics on sonar signal design. *Behavioral ecology and sociobiology*. 36(3): 207-219.

Obrist MK, Rathey E, Bontadina F, Martinoli A, Conedera M, Christe, P, and M Moretti. 2011. Response of bat species to sylvo-pastoral abandonment. *Forest Ecology and Management*. *261*(3): 789–798.

Ochoa G J. O'Farrell MJ, and BW Miller. 2000. Contribution of acoustic methods to the study of insectivorous bat diversity in protected areas from northern Venezuela. *Acta Chiropterologica.* 2(2): 171-183.

O'Farrell MJ and WG Bradley. 1970. Activity patterns of bats over a desert spring. *Journal of Mammology*. 51(1): 18-26.

O'Farrell MJ and WL Gannon. 1999. A comparison of acoustic versus capture techniques for the inventory of bats. *Journal of Mammalogy*. 80(1): 24-30.

Ozawa J, Ryan P and M Grueber. The 2016 U.S. golf economy report. Accessed at: https://golf2020.com/research/ on March 1st 2019.

Patriquin KJ and RMR Barclay. 2003. Foraging by bats in cleared, thinned, and unharvested boreal forest. *Journal of Applied Ecology*. 40(4): 646-657.

Pinheiro J, Bates D, Debroy S, Sarkar D, and R Development Core Team. 2012. nlme: Linear and Nonlinear Mixed Effects Models. R package version 3.1–105.

Platt A E. 1994. Toxic green: the trouble with golf. *World Watch*. 7(3): 27.

R Core Team. 2018. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing. Vienna, Austria. https://www.R-project.org

R Studio Team. 2016. RStudio: Integrated Development Environment for R. R Studio, Inc. Boston, Massachusetts, USA. http://www.rstudio.com/

Rainwater TR, Leopold VA, Hooper MJ and RJ Kendall. 1995. Avian exposure to organophosphorus and caramate pesticides on a coastal South Carolina golf course. *Environmental Toxicology and Chemistry: An Internal Journal*. 14(12): 2155-2161.

Reeder DM, Frank CL, Turner GG, Meteyer CU, Kurta A, Britzke ER, Vodzak ME, Darlin SR, Stihler CW, Hicks AC and R Jacob. 2012. Frequent arousal from hibernation linked to severity of infection and mortality in bats with white-nose syndrome. *PLoS One.* 7(6): e38920.

Reichard JD, and TH Kunz. 2009. White-nose syndrome inflicts lasting injuries to the wings of little brown myotis (*Myotis lucifugus*). *Acta Chiropterologica.* 11: 457-464.

Reichert, B, and Lausen C, Loeb S, Weller T, Allen R, Britzke E, Hohoff T, Siemers J, Burkholder B, Herzog C, and M Verant. 2018, A Guide to processing bat acoustic data for the North American Bat Monitoring Program (NABat): U.S. Geological Survey Open-File Report 2018–1068, 33 p.

Shump KA and AU Shump. 1982. *Lasiurus borealis*. *Mammalian Species*. 183: 1-6.

Smith MD, Conway CJ, and LA Ellis. 2005. Burrowing owl nesting productivity: a comparison between artificial and natural burrows on and off golf courses. *Wildlife Society Bulletin. 33(2): 454-462.*

SRI International for World Golf Foundation and GOLF 20/20. 2011. Golf Economy Report. 1-15.

Stanback MT and ML Seifert. 2005. A comparison of eastern bluebird reproductive parameters in golf and rural habitats. *Wildlife Society Bulletin*. 33(2): 471-482.

Stansley, W, Roscoe DE, Hawthorne E, and R Meyer. 2001. food chain aspects of chlordane poisoning in birds and bats. *Archives of Environmental Contamination and Toxicology*. 40: 285-291.

Stuller J. 1997. Golf gets back to nature, inviting everyone to play. *Smithsonian.* 28(1): 56-58.

Suzuki T, Kondo H, Yaguchi K, Maki T, and T Suga. 1998. Estimation of leachability and persistence of pesticides at golf courses from point-source monitoring and model to predict pesticide leaching to groundwater. *Environmental Science and Technology.* 32: 920-929.

Szewczak JM. 2004. Advanced analysis techniques for identifying bat species. *Bat echolocation research: tools, techniques and analysis.* Bat Conservation International. Austin, Texas, USA: 121-126

Tanner, RA, and AC Gange. 2004. Effects of golf courses on local biodiversity. *Landscape and Urban Planning*. 71: 137-146.

Terman M. 1997. Naturalistic links: naturalistic golf courses as wildlife habitat. *Landscape and Urban Planning.*38: 183-197.

Threlfall, CG, Mata, L, Mackie J, et al. 2017. Increasing biodiversity in urban green spaces through simple vegetation interventions. *Journal of Applied Ecology*. J Appl Ecol.

Tilman D, May RM, Lehman CL, and MA Nowak. 1994. Habitat destruction and the extinction debt. *Nature*. 371: 65-66.

de Torrez ECB, Wallrichs MA, Ober H K, and RA McCleery, 2017. Mobile acoustic transects miss rare bat species: implications of survey method and spatio-temporal sampling for monitoring bats. *PeerJ*, *5*, e3940.

Turner GG, Reeder DM, and Coleman JTH. 2011. A five-year assessment of mortality and geographic spread of white-nose syndrome in North American bats and a look to the future. *Bat Research News*. 52: 13-27.

U.S. Department of Agriculture. 2018. Fertilizer use and price. Excel spreadsheet accessed from: https://www.ers.usda.gov/data-products/fertilizer-use-and-price/ on March 1 2019.

U. S. Fish and Wildlife Service. 2011. News Release: North American bat death toll exceeds 5.5 million from white-nose syndrome. https://s3.amazonaws.com/org.whitenosesyndrome.assets/prod/0ce91f80-78ad-11e8-b37b-4f3513704a5e-wns_mortality_2012_nr_final.pdf

U. S. Fish and Wildlife Service. 2012. White-nose-Syndrome Decontamination Protocol: http://whitenosesyndrome.org/sites/default/files/resource/national_wns_revise_final_6.25.12.pdf

Vandevelde J-C, Bouhours A, Julien J-F, Couveta D and C Kerbirioua. 2014. Activity of European common bats along railway verges. *Ecologicl Engineering*. 64: 49-56.

Vaughan N, Jones G, Harris S. 1997. Habitat use by bats (Chiroptera) assesed by means of broad-band acoustic method. *Journal of Applied Ecology*. 34(3): 716-730.

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: 1393-1401.

Vindigni MA, Morris AD, Miller DA, and MC Kalcounis-Rueppell. 2009. Use of modified water sources by bats in a managed pine landscape. *Forest Ecology and Management.* 258(9): 2056-2061.

Voigt CC, Schneeberger K, Voigt-Heucke, SL, and D Lewanzik. 2011. Rain increases the energy cost of bat flight. *Biology letters*, 7(5), 793-795.

Walsh AL, and S Harris. 1996. Foraging Habitat Preferences of Vespertilionid Bats in Britain. *Journal of Applied Ecology*. 33(3): 508-518.

Wheeler K, and J Nauright. 2006. A global perspective on the environmental impact on golf. *Sport in Society*. 9(3): 427-443.

Whitaker Jr, TO, and P Clem. 1992. Food of the evening bat *Nycticeius humeralis* from Indiana. *American Midland Naturalist*. 127(1): 211-214.

White DH, Mitchell CA, and RM Prouty. 1983. Nesting biology of laughing gulls in relation to agricultural chemicals in south texas, 1978-81. *The Wilson Bulletin*. 95(4): 540-551.

White-nose Syndrome Response Team. 2018. WNS Spread Maps. Accessed March 1st 2019: https://www.whitenosesyndrome.org/mmedia-education/october-10-2018

Williams-Guillen K, Perfecto I, and J Vandermeer. 2008. Bats limit insects in a neotropical agroforestery system. *Science*. 320 (5872): 70-70.

Winter JG, Dillon PJ, Paterson C, Reid RA, and KM Somers. 2003. Impacts of golf course construction and operation on headwater streams: bioassessment using benthic algae. *Canadian Journal of Botany*. 81(8): 848-858.

Winter JG, and PJ Dillion. 2005. Effects of golf course construction and operation on water chemistry of headwater streams on the Precambrian Shield. *Environmental Pollution*. 133: 243-253.

Wolbert SJ, Zellner AS and HP Whidden. 2014. Bat activity, insect biomass, and temperature along an elevational gradient. *Northeastern Naturalist*. 21(1):72-85.

Wolcott KA, and K Vulinec. 2012. Bat activity at woodland/farmland interfaces in central Delaware. *Northeastern Naturalist.* 19(1): 87-98.

Wray AK, Jusino MA, Banik MT, Palmer JM, Kaarakka H, White JP, Lindner DL, Gratton C. and MZ Peer. 2018. Incidence and taxonomic richness of mosquitoes in the diets of little brown and big brown bats. *Journal of Mammology*. 99(3): 668-674.

Zinkl JG, Rathert J, and RR Hudson. 1978. Diazinon poisoning in wild Canada geese. *The Journal of Wildlife Mangagement.* 42(2): 406-408.